Water Quality Technical Report

Water Quality Impacts from Coal Bed Methane Development in the Powder River Basin, Wyoming and Montana

December 18, 2001

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Objective of this analysis

This analysis is intended to assess how discharges from Coal Bed Methane (CBM) wells in Wyoming and Montana may, due to their cumulative effects on water quality, impact irrigation, riparian plant communities, and aquatic resources.[1] Since some contaminants in CBM discharges, if undiluted, are known to have adverse effects, the questions addressed are: 1) in which streams would CBM produced water cause unacceptable adverse impacts, and 2) by what amount would the discharge need to be limited in order to avoid adverse impact. To assess these impacts, it is necessary to establish the threshold values for the significant effects of certain contaminants found in CBM discharges, as described in more detail below.

Background Discussion and Development of Threshold Water Quality Values to Protect Irrigation Uses

The Montana Department of Environmental Quality (MDEQ) regulates discharges of CBM-produced water pursuant to the Federal Clean Water Act and State Law. MDEQ issues discharge permits, which contain technology-based requirements and water quality standard-based effluent limits, as appropriate. Water quality standards are adopted to protect all existing and designated beneficial uses. Irrigated agriculture is expected to be the beneficial use most sensitive to the effects of CBM produced water and, for that use, the two principal CBM constituents of concern are SAR[2] and salinity.

SAR is an expression of the concentration of sodium relative to the sum of the concentrations of calcium and magnesium in water. SAR adversely affects the physical properties of soil resulting in deterioration of soil hydraulic characteristics. Salinity is expressed as electrical conductance, EC, in units of dS/m or μS/cm, or as total dissolved solids, TDS, in units of mg/l.

[1] In addition, the quantities of water discharged from Coal Bed Methane wells may also have adverse environmental impacts, which are not addressed in this paper.
[2] SAR means sodium adsorption ratio. SAR is sometimes reported by the symbol RNs. SAR = sodium/ (the square root of ((calcium+magnesium)/2)) where all concentrations are in milliequivalents per liter. At a given SAR, harmful effects of SAR decrease as water salinity increases.

The State of Montana currently does not have numerical standards for either SAR or salinity[3] and, because of the site-specific nature of these two constituents, EPA has not developed national criteria recommendations for SAR and salinity for the protection of irrigated agriculture. In order to assess the potential cumulative impacts to irrigated agriculture, an evaluation of SAR and salinity effects is necessary. Therefore numerical "effect thresholds" for SAR and salinity appropriate for protection of irrigated agriculture in the Tongue, Powder, Little Powder and Little Big Horn river basins and Rosebud Creek will be established.

In establishing allowable SAR and salinity thresholds for protection of irrigated agriculture and/or land application of discharge water, there are a number of inter-related factors to be considered, including the crop and/or native plant species that will be irrigated or exposed to these conditions. The texture of the irrigated soils, predominant clay mineralogy, soil chemistry, water management practices, and the chemistry of the irrigation water are also important. Elevated SAR can destroy the structure of clayey soils, and montmorillonite clays are particularly sensitive to the effects of elevated SAR. Montmorillonite clays are common in the river basins that will be potentially impacted by CBM development and, because of the complexity of the soil associations, with several soil types possible within a single field, the allowable SAR and salinity thresholds protect the most sensitive soil type, which is montmorillonite clays.

Development of allowable SAR and salinity thresholds is further complicated by the relationship between SAR and salinity, and the direct toxicity of sodium and salinity to certain plants. There is a well-recognized relationship between SAR and salinity, with the potential impacts of SAR becoming less severe as salinity increases. That is, as the electrolyte concentration of the soil solution increases, the effect of sodium-induced changes in soil structure is reduced. Although this might initially suggest that the SAR "problem" could be managed by artificially increasing the salinity of the irrigation water, there are several factors that weigh against such a management approach. First, there is a point at which salinity itself becomes a problem. Salinity problems are especially important for plants at the germination, emergence and seedling stages. Second, the potential of direct sodium toxicity argues for an upper bound on the allowable SAR threshold value as well. Finally, and perhaps more importantly, because of the inter-active relationship between SAR and salinity, an appropriate SAR threshold must be paired with a corresponding salinity value. That is, the relationship between SAR and salinity is a dynamic one, and as the salinity concentration changes, so does the allowable SAR. As explained in more detail below, these factors were considered in developing the allowable SAR and salinity "effect thresholds" used in this report.

As part of the NEPA and MEPA process, federal and state agencies must consider the cumulative impacts of their proposed actions. In the case of CBM development this includes developing impact thresholds or criteria at which significant impacts from CBM production water to beneficial uses, such as agriculture, may result. These threshold values may be different for different basins or streams.

The first step in that evaluation is to describe the scientific relationship between a use of water and the concentration or level of a parameter that could affect that use. The effects of salinity, expressed as EC,

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[3] Montana DEQ intends to develop numerical standards for SAR and salinity and will begin the water quality standards development process in December, 2001 with a series of scoping meetings.

and the SAR of the irrigation water on soils and crop production are dependent on the interaction of several factors.

The characteristics of the soils, especially the amount of clay present in the soils, are important factors. Significant amounts of clay restrict the amount of leaching that can occur and leaching is an important factor in determining the effects of salinity on crop production. In addition, soils with a large amount of clay are more susceptible to damage from elevated levels of SAR than soils with little clay.

Furthermore, the way in which irrigation is done may have significant effects on crop production.

These factors and their interactions have been summarized, principally, from two sources. They are Hansen, B.R., S. R. Gratton, and A. Fulton. *AGRICULTURAL SALINITY AND DRAINAGE, University of California Irrigation Program*, University of California, Davis, revised 1999 and, R. S. Ayers and D. W. Westcot, *Water Quality for Agriculture*, FAO Irrigation and Drainage paper 29 (Rev 1), Food and Agriculture Organization of the United Nations, 1985.

Table 1, adapted from from Ayers and Westcot, gives guidelines for water quality for irrigation. The reader should bear in mind that these are guidelines and not absolute values. The reader should also read the footnote and the basic assumptions carefully.

Table 1.

GUIDELINES FOR INTERPRETATIONS OF WATER QUALITY FOR IRRIGATION

			Degree of Restriction on Use	
Potential Irrigation Problem Salinity *(affects crop water availability)*	Units	None	Slight to Moderate	Severe
EC	dS/m	< 0.7	0.7 - 3.0	> 3.0
(or) TDS	mg/l	<450	450 - 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil . Evaluate using EC_w[4] and SAR together)*				
SAR = 0 - 3 and EC_w =		>0.7	0.7 - 0.2	< 0.2
SAR = 3 -6 and EC_w =		>1.2	1.2 - 0.3	< 0.3
SAR = 6 - 12 and EC_w =		>1.9	1.9 - 0.5	< 0.5
SAR = 12-20 and EC_w =		>2.9*	2.9 - 1.3	< 1.3
SAR = 20-40 and EC_w =		>5.0*	5.0 - 2.9	< 2.9

*The EC of these waters will restrict their use.

The water quality guidelines in Table 1 are intended to cover the wide range of conditions encountered in irrigated agriculture. Several basic assumptions (given below) have been used to define their range of usability. If the water is used under greatly different conditions, the guidelines may need to be adjusted. Wide deviations from the assumptions might result in inaccurate judgements on the usability of a particular water supply, especially if it is a borderline case. Where sufficient experience, field trials, research or observations are available, the guidelines may be modified to fit local conditions more closely.

The basic assumptions in these guidelines are:

Yield Potential: Full production capability of all crops, without the use of special practices, is assumed when the guidelines indicate no restrictions on use. A "restriction on use" indicates that there may be a limitation in choice of crop, or special management may be needed to maintain full production capability. A "restriction on use" does not indicate that the water is unsuitable for use.

Site Conditions: Soil texture ranges from sandy-loam to clay-loam with good internal drainage. The climate is semi-arid to arid. Rainfall does not play a significant role in meeting crop water demand or

[4] EC_w means the average EC of the irrigation water

leaching requirement. (In a monsoon climate or areas where precipitation is high for part or all of the year, infiltrated water from rainfall is effective in meeting all or part of the leaching requirement.) drainage is assumed to be good, with no uncontrolled shallow water table present within 2 meters of the surface.

Methods and Timing of Irrigation: Normal surface or sprinkler irrigation methods are used. Water is applied infrequently, as needed, and the crop utilizes a considerable portion of the available stored soil-water (50 percent or more) before the next irrigation. At least 15 percent of the applied water percolates below the root zone (leaching fraction [LF]=15 percent). The guidelines are too restrictive for specialized irrigation methods, such as localized drip irrigation, which results in near daily or frequent irrigations, but are applicable for subsurface irrigation if surface applied leaching water satisfies the leaching requirements.

Water Uptake by Crops: Different crops have different water uptake patterns, but all take water from wherever it is most readily available within the rooting depth. On average, about 40 percent is assumed to be taken from the upper quarter of the rooting depth, 30 percent from the second quarter, 20 percent from the third quarter, and 10 percent from the lowest quarter. Each irrigation leaches the upper root zone and maintains it at a relatively low salinity. Salinity increases with depth and is greatest in the lower part of the root zone. The average salinity of the soil-water is three times that of the applied water and is representative of the average root zone salinity to which the crop responds. These conditions result from a leaching fraction of 15-20 percent and irrigations that are timed to keep the crop adequately watered at all times.

Salts leached from the upper root zone accumulate to some extent in the lower part, but a salt balance is achieved as salts are moved below the root zone by sufficient leaching. The higher salinity in the lower root zone becomes less important if adequate moisture is maintained in the upper, "more active" part of the root zone and long-term leaching is accomplished.

Restriction on Use: The "Restriction on Use" shown in Table 1 is divided into three degrees of severity: none, slight to moderate, and severe. The divisions are somewhat arbitrary since change occurs gradually and there is no clear-cut breaking point. A change of 10 to 20 percent above or below a guideline value has little significance if considered in proper perspective with other factors affecting yield. Field studies, research trials and observations have led to these divisions, but management skill of the water user can alter them. Values shown are applicable under normal field conditions prevailing in most irrigated areas in the arid and semi-arid regions of the world.

Salinity

Salinity refers to the amount of dissolved solids in water and is generally expressed as parts per million (ppm) total dissolved solids (TDS). Electrical Conductance (EC) can also be used as a measure of salinity and is considerably cheaper and easier to measure and monitor. EC will be used in this discussion.

It is important to note that soil scientists express EC in terms of deciSiemens per meter (dS/m) while water quality results are expressed as microSiemens per centimeter (μS/cm). One dS/m equals 1000 μS/cm. Thus, when the water of the Tongue River has an EC of 700 μS/cm it also has an EC of 0.7 dS/m.

Plants expend energy to extract water from soil. As the salinity of the water in the soil increases, the energy needed to extract water also increases. At some point, which varies with the type of crop, further increases in salinity will result in a decrease in crop production.

The composition of the soil, the salinity of the irrigation water, and the amount of irrigation water (and precipitation) that passes through the soil determine the salinity of the water in the soil. Due to the arid conditions in the Powder River Basin, precipitation in the irrigated areas generally has little effect on the salinity of the soil water, and these effects will not be discussed.

Salts in the water may be precipitated in the soil and salts in the soil may be dissolved by the water. These processes are determined primarily by the composition of the soil. However, due to the complexities and site specific nature of these processes they will not be discussed here except to note that overall, the total concentration of salts in the soil water is likely to be increased by contact with the soil.

The percentage of applied water that passes through the soil is called the leaching fraction. The salinity of the irrigation water and the leaching fraction are the most important factors affecting the salinity of the soil water. The salinity of the soil water is important, since the salinity of the soil water, rather than the salinity of the irrigation water itself, is the critical factor resulting in any decrease in crop yield. Continued irrigation will result in the salinity of the soil water coming into equilibrium with the salinity of the irrigation water. The actual relationship will be dependent on the average salinity of the irrigation water and the actual leaching fraction.

The relationship between soil water salinity and crop yield will be discussed first and then the relationship between irrigation water salinity and soil water salinity will be discussed.

Crop yield

Table 2 (Table 4 in Ayers and Westcot) can be used to estimate the expected yields for selected crops that are grown using water with differing levels of salinity.

Table 2.

Table 4 CROP TOLERANCE AND YIELD POTENTIAL OF SELECTED CROPS AS INFLUENCED BY IRRIGATION WATER SALINITY (EC_w) OR SOIL SALINITY (EC_e)[1]

YIELD POTENTIAL[2]

FIELD CROPS	100%		90%		75%		50%		0% "maximum"[3]	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Barley *(Hordeum vulgare)*[4]	8.0	5.3	10	6.7	13	8.7	18	12	28	19
Cotton *(Gossypium hirsutum)*	7.7	5.1	9.6	6.4	13	8.4	17	12	27	18
Sugarbeet *(Beta vulgaris)*[5]	7.0	4.7	8.7	5.8	11	7.5	15	10	24	16
Sorghum *(Sorghum bicolor)*	6.8	4.5	7.4	5.0	8.4	5.6	9.9	6.7	13	8.7
Wheat *(Triticum aestivum)*[4,6]	6.0	4.0	7.4	4.9	9.5	6.3	13	8.7	20	13
Wheat, durum *(Triticum turgidum)*	5.7	3.8	7.6	5.0	10	6.9	15	10	24	16
Soybean *(Glycine max)*	5.0	3.3	5.5	3.7	6.3	4.2	7.5	5.0	10	6.7
Cowpea *(Vigna unguiculata)*	4.9	3.3	5.7	3.8	7.0	4.7	9.1	6.0	13	8.8
Groundnut (Peanut) *(Arachis hypogaea)*	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	6.6	4.4
Rice (paddy) *(Oriza sativa)*	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	11	7.6
Sugarcane *(Saccharum officinarum)*	1.7	1.1	3.4	2.3	5.9	4.0	10	6.8	19	12
Corn (maize) *(Zea mays)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Flax *(Linum usitatissimum)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Broadbean *(Vicia faba)*	1.5	1.1	2.6	1.8	4.2	2.0	6.8	4.5	12	8.0
Bean *(Phaseolus vulgaris)*	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.3	4.2
VEGETABLE CROPS										
Squash, zucchini (courgette) *(Cucurbita pepo melopepo)*	4.7	3.1	5.8	3.8	7.4	4.9	10	6.7	15	10
Beet, red *(Beta vulgaris)*[5]	4.0	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15	10
Squash, scallop *(Cucurbita pepo melopepo)*	3.2	2.1	3.8	2.6	4.8	3.2	6.3	4.2	9.4	6.3
Broccoli *(Brassica oleracea botrytis)*	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	14	9.1
Tomato *(Lycopersicon esculentum)*	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	13	8.4
Cucumber *(Cucumis sativus)*	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10	6.8
Spinach *(Spinacia oleracea)*	2.0	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15	10
Celery *(Apium graveolens)*	1.8	1.2	3.4	2.3	5.8	3.9	9.9	6.6	18	12
Cabbage *(Brassica oleracea capitata)*	1.8	1.2	2.8	1.9	4.4	2.9	7.0	4.6	12	8.1
Potato *(Solanum tuberosum)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Corn, sweet (maize) *(Zea mays)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Sweet potato *(Impomoea batatas)*	1.5	1.0	2.4	1.6	3.8	2.5	6.0	4.0	11	7.1
Pepper *(Capsicum annuum)*	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.6	5.8
Lettuce *(Lactuca sativa)*	1.3	0.9	2.1	1.4	3.2	2.1	5.1	3.4	9.0	6.0
Radish *(Raphanus sativus)*	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3.4	8.9	5.9
Onion *(Allium cepa)*	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.4	5.0
Carrot *(Daucus carota)*	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.0	8.1	5.4
Bean *(Phaseolus vulgaris)*	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.3	4.2
Turnip *(Brassica rapa)*	0.9	0.6	2.0	1.3	3.7	2.5	6.5	4.3	12	8.0

Table 4 (continued)

YIELD POTENTIAL

FORAGE CROPS	100% EC_e	100% EC_w	90% EC_e	90% EC_w	75% EC_e	75% EC_w	50% EC_e	50% EC_w	0% "maximum"[3] EC_e	0% "maximum"[3] EC_w
Wheatgrass, tall *(Agropyron elongatum)*	7.5	5.0	9.9	6.6	13	9.0	19	13	31	21
Wheatgrass, fairway crested *(Agropyron cristatum)*	7.5	5.0	9.0	6.0	11	7.4	15	9.8	22	15
Bermuda grass *(Cynodon dactylon)*[7]	6.9	4.6	8.5	5.6	11	7.2	15	9.8	23	15
Barley (forage) *(Hordeum vulgare)*[4]	6.0	4.0	7.4	4.9	9.5	6.4	13	8.7	20	13
Ryegrass, perennial *(Lolium perenne)*	5.6	3.7	6.9	4.6	8.9	5.9	12	8.1	19	13
Trefoil, narrowleaf birdsfoot[8] *(Lotus corniculatus tenuifolium)*	5.0	3.3	6.0	4.0	7.5	5.0	10	6.7	15	10
Harding grass *(Phalaris tuberosa)*	4.6	3.1	5.9	3.9	7.9	5.3	11	7.4	18	12
Fescue, tall *(Festuca elatior)*	3.9	2.6	5.5	3.6	7.8	5.2	12	7.8	20	13
Wheatgrass, standard crested *(Agropyron sibiricum)*	3.5	2.3	6.0	4.0	9.8	6.5	16	11	28	19
Vetch, common *(Vicia angustifolia)*	3.0	2.0	3.9	2.6	5.3	3.5	7.6	5.0	12	8.1
Sudan grass *(Sorghum sudanense)*	2.8	1.9	5.1	3.4	8.6	5.7	14	9.6	26	17
Wildrye, beardless *(Elymus triticoides)*	2.7	1.8	4.4	2.9	6.9	4.6	11	7.4	19	13
Cowpea (forage) *(Vigna unguiculata)*	2.5	1.7	3.4	2.3	4.8	3.2	7.1	4.8	12	7.8
Trefoil, big *(Lotus uliginosus)*	2.3	1.5	2.8	1.9	3.6	2.4	4.9	3.3	7.6	5.0
Sesbania *(Sesbania exaltata)*	2.3	1.5	3.7	2.5	5.9	3.9	9.4	6.3	17	11
Sphaerophysa *(Sphaerophysa salsula)*	2.2	1.5	3.6	2.4	5.8	3.8	9.3	6.2	16	11
Alfalfa *(Medicago sativa)*	2.0	1.3	3.4	2.2	5.4	3.6	8.8	5.9	16	10
Lovegrass *(Eragrostis sp.)*[9]	2.0	1.3	3.2	2.1	5.0	3.3	8.0	5.3	14	9.3
Corn (forage) (maize) *(Zea mays)*	1.8	1.2	3.2	2.1	5.2	3.5	8.6	5.7	15	10
Clover, berseem *(Trifolium alexandrinum)*	1.5	1.0	3.2	2.2	5.9	3.9	10	6.8	19	13
Orchard grass *(Dactylis glomerata)*	1.5	1.0	3.1	2.1	5.5	3.7	9.6	6.4	18	12
Foxtail, meadow *(Alopecurus pratensis)*	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5	12	7.9
Clover, red *(Trifolium pratense)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, alsike *(Trifolium hybridum)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, ladino *(Trifolium repens)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, strawberry *(Trifolium fragiferum)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
FRUIT CROPS[10]										
Date palm *(Phoenix dactylifera)*	4.0	2.7	6.8	4.5	11	7.3	18	12	32	21
Grapefruit *(Citrus paradisi)*[11]	1.8	1.2	2.4	1.6	3.4	2.2	4.9	3.3	8.0	5.4
Orange *(Citrus sinensis)*	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8.0	5.3
Peach *(Prunus persica)*	1.7	1.1	2.2	1.5	2.9	1.9	4.1	2.7	6.5	4.3
Apricot *(Prunus armeniaca)*[11]	1.6	1.1	2.0	1.3	2.6	1.8	3.7	2.5	5.8	3.8
Grape *(Vitus sp.)*[11]	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5	12	7.9
Almond *(Prunus dulcis)*[11]	1.5	1.0	2.0	1.4	2.8	1.9	4.1	2.8	6.8	4.5

Table 4 (continued)

FRUIT CROPS [10]	YIELD POTENTIAL 100% EC_e	100% EC_w	90% EC_e	90% EC_w	75% EC_e	75% EC_w	50% EC_e	50% EC_w	0% "maximum"[3] EC_e	0% "maximum"[3] EC_w
Plum, prune *(Prunus domestica)*[11]	1.5	1.0	2.1	1.4	2.9	1.9	4.3	2.9	7.1	4.7
Blackberry *(Rubus sp.)*	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6.0	4.0
Boysenberry *(Rubus ursinus)*	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6.0	4.0
Strawberry *(Fragaria sp.)*	1.0	0.7	1.3	0.9	1.8	1.2	2.5	1.7	4	2.7

1 Adapted from Maas and Hoffman (1977) and Maas (1984). These data should only serve as a guide to relative tolerances among crops. Absolute tolerances vary depending upon climate, soil conditions and cultural practices. In gypsiferous soils, plants will tolerate about 2 dS/m higher soil salinity (ECe) than indicated but the water salinity (ECw) will remain the same as shown in this table.

2 ECe means average root zone salinity as measured by electrical conductivity of the saturation extract of the soil, reported in deciSiemens per metre (dS/m) at 25°C. ECw means electrical conductivity of the irrigation water in deciSiemens per metre (dS/m). The relationship between soil salinity and water salinity (ECe = 1.5 ECw) assumes a 15-20 percent leaching fraction and a 40-30-20-10 percent water use pattern for the upper to lower quarters of the root zone. These assumptions were used in developing the guidelines in Table 1.

3 The zero yield potential or maximum ECe indicates the theoretical soil salinity (ECe) at which crop growth ceases.

4 Barley and wheat are less tolerant during germination and seedling stage; ECe should not exceed 4-5 dS/m in the upper soil during this period.

5 Beets are more sensitive during germination; ECe should not exceed 3 dS/m in the seeding area for garden beets and sugar beets.

6 Semi-dwarf, short cultivars may be less tolerant.

7 Tolerance given is an average of several varieties; Suwannee and Coastal Bermuda grass are about 20 percent more tolerant, while Common and Greenfield Bermuda grass are about 20 percent less tolerant.

8 Broadleaf Birdsfoot Trefoil seems less tolerant than Narrowleaf Birdsfoot Trefoil.

9 Tolerance given is an average for Boer, Wilman, Sand and Weeping Lovegrass; Lehman Lovegrass seems about 50 percent more tolerant.

10 These data are applicable when rootstocks are used that do not accumulate Na^+ and Cl^- rapidly or when these ions do not predominate in the soil. If either ions do, refer to the toxicity discussion in Section 4.

11 Tolerance evaluation is based on tree growth and not on yield.

Alfalfa, a major irrigated crop in the Powder River Basin (PRB), will be used as an example to help explain the information in this table. In Table 2 the column titled “100%” and subtitled “EC_e”, the value for alfalfa is 2.0 dS/m. This means that as long as the average EC of the soil water in the root zone does not exceed 2.0 dS/m (or 2000 μS/cm), the salinity of the water will not cause a decrease in yield. Likewise, when the average EC of the soil water (EC_e) reaches 3.4 dS/m, the salinity by itself will cause a 10 percent decrease in yield and an EC_e of 8.8 dS/m will cause a 50% decrease in yield.

In Table 2, the values for EC_w are the average concentration of the irrigation water that will result in the corresponding EC_e. Footnote 2 points out that these EC_w values or irrigation water electrical conductance values are based on an assumed leaching fraction of 15 to 20 percent. This means that, for alfalfa, if the EC of the irrigation water is 1,300 μS/cm or less and the leaching fraction is 20 percent, the salinity of the soil water would be 2,000 μS/cm and there would be no decrease in yield.

For alfalfa irrigated with an EC_w near 1,300 μ/cm (1.3 dS/m), the leaching fraction must be at least 15 to 20 percent to prevent effects on yield. In other words, if the crop needs 24 inches of water per season then 24 inches plus 20 percent (4.8) or a total of 28.8 inches of water must be applied in order to maintain maximum yield. If the irrigation water salinity is greater than 1,300 μs/cm or the leaching fraction is less than 20 percent, yields will be decreased. There would be a 10 percent yield decrease if the average irrigation water conductivity were 2,200 μS/cm (2.2 dS/m) and a 25 percent yield decrease if the average irrigation water conductivity is 3,600 μS/cm (3.6 dS/m). In order to determine the effects of changing the leaching fraction, an extra step is required.

Figure 1, from Hansen et al., gives the relationship between the EC of the irrigation water and the EC of the soil water at various leaching fractions. Note that an irrigation water EC of 1.3 dS/m and a leaching fraction of 20% results in an "average root zone" EC of 2 dS/m. The "average root zone" EC is the same as the salinity of the soil water. By using Figure 1, it can be seen that if the EC of the irrigation water is 1.3 dS/m and the leaching fraction is 5%, the resulting soil water salinity will be about 3.6 dS/m. According to Table 2, this corresponds to about a 25% reduction in yield. If the leaching fraction is 40%, then the irrigation water EC could be as high as 2 dS/m without causing decreases in yield.

These are all approximate values and assume that sufficient water can pass through the root zone of the irrigated soils. This should not be a problem for most soils for the lower leaching requirements. However, it may be difficult to pass sufficient water through the root zone to achieve the higher leaching fractions, especially in "heavy” soils (soils with a high content of clay). In addition, these tables assume that sufficient water is physically and legally available for the increased leaching. Increasing the leaching fraction from 20 to 40 percent would require 20% more water.

Further, while it is assumed that leaching is uniform throughout a field, in practice the leaching fraction is not uniform throughout a field. First of all, there are usually differences in the soil characteristics within a field. Thus, there are likely to be differences in the rate at which water flows through the root zone in different parts of a field because the soil texture and thus the permeability of the soils varies. Secondly, the rate at which water enters the soil at a particular point is partially determined by the water pressure or depth of water at that point. Fields are seldom level. Less water will enter the soils in the "high spots" (a few inches can make a difference) of the field where the depth of water will be least. Most importantly, the amount of leaching that occurs is dependent on the time that excess water is

Figure 1.

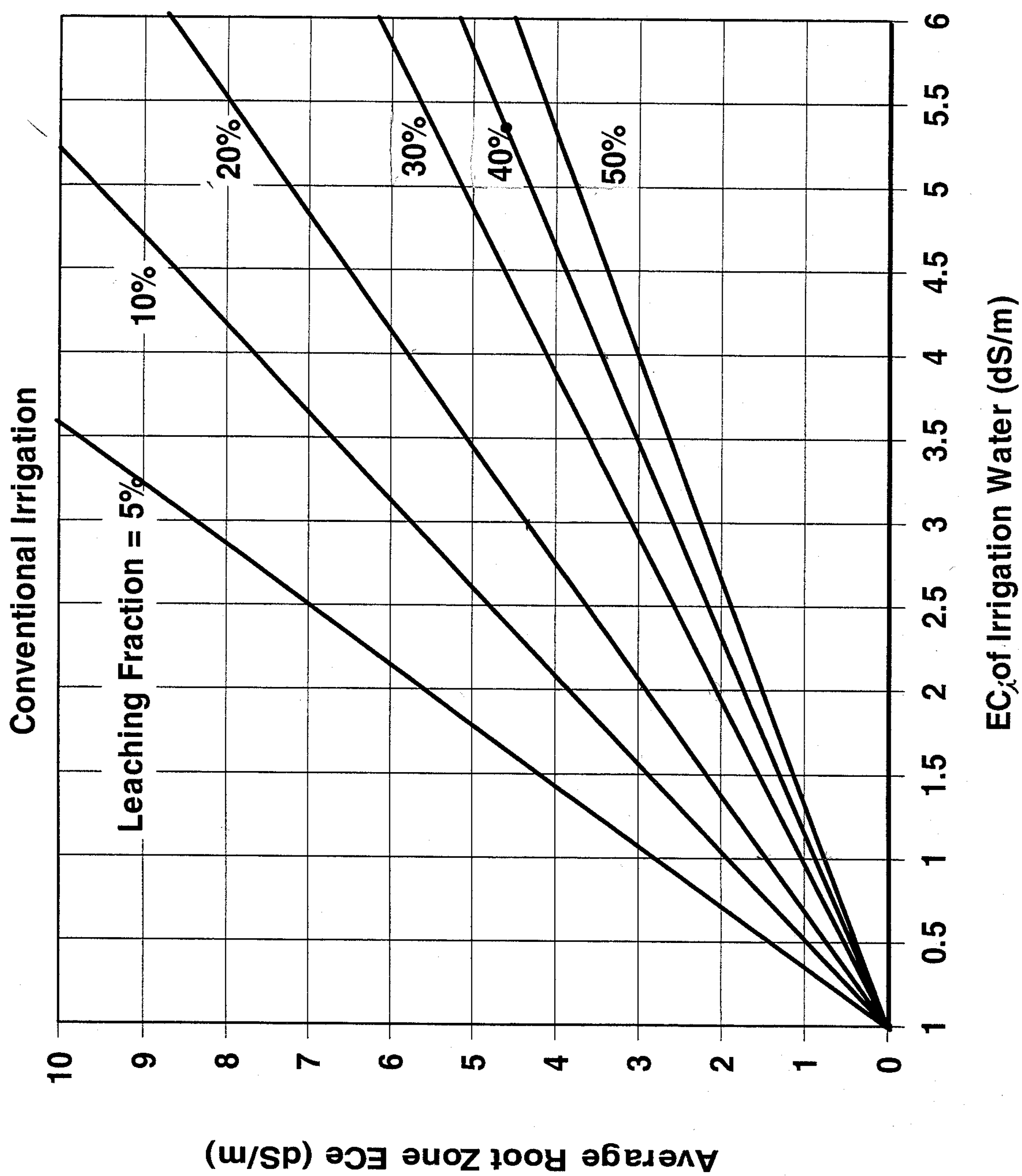

Figure 1. Assessing the maintenance leaching fraction under conventional irrigation methods.

applied to the soil. During conventional flood irrigation, the soils in the upper part of a field near the ditches will be covered with water much longer than the soils at the bottom or tail end of a field.

The problems of low permeability, high spots, and differences in the length of time water is applied to different parts of a field can be overcome by diking an entire field (like a rice paddy) and covering it with water for as long as necessary to achieve the desired leaching. This assumes that the crop can tolerate being submerged for a sufficient length of time and that it is physically possible to flood the entire field. This type of irrigation is used in the Powder River and Little Powder River drainages and on some tributaries throughout the PRB. Most of the irrigators on the Tongue River and other high quality waters use conventional irrigation methods.

As is mentioned above, the quality of the irrigation water is a critical factor that may affect crop yields. The current EC of the Tongue River, and some of the other high quality streams, is consistently less than 1000 μS/cm. Thus, it is likely that in these watersheds the average EC could be increased to 1000 μS/cm or perhaps even to 1300 μS/cm without causing a decrease in the yield of alfalfa.

However, in the other drainages such as the Powder and Little Powder the EC is such that using water with average quality (2000 to 2200 μS/cm) and conventional irrigation methods would result about a 10 percent decrease in the yield of alfalfa. If, due to current irrigation methods, the actual leaching fraction is 40 percent then there is no decrease in yield. In essentially all of the PRB the amount of irrigation is limited by the shortage of available water. This shortage is particularly acute in the drainages with the higher ECs. As a result, the irrigators where the water has high ECs irrigate when water is available <u>provided</u> that they can use it then and <u>provided</u> that they think the water's quality is acceptable. Thus, average instream water quality may not reflect the quality of the water actually used for irrigation. At the present time there does not seem to be a way of determining the actual mean quality of the water that is used for irrigation in these drainages.

<u>Salinity threshold values</u>

Based on the considerations given above and given the need to provide an assessment of potential impacts, a salinity value of 1000 μS/cm is a reasonable estimate of an effect threshold and is an appropriate benchmark for estimating the potential impact of CBM discharges to the Tongue and Little Bighorn Rivers, and Rosebud Creek.

Similarly, the appropriate effects threshold for the Powder and Little Powder Rivers and Mizpah Creek and their tributaries (and the tributaries to the Tongue River) is 2000 μS/cm. This threshold is based on the current average water quality and assumes that an average leaching fraction of 40 percent is being achieved in these watersheds.

Because these thresholds are based on impacts to irrigation they would apply from March through September. The suggested salinity threshold of 2000 μS/cm is about the same as the average quality of the current CBM discharges in Montana. If in fact, the water that is actually being used for irrigation is substantially better than the average water quality of the streams this threshold may be too high.

Development of Sodium Adsorption Ratio (SAR) threshold values

The clay portion of soils consists of very small plate-like structures stacked like decks of cards. Water in soil moves, and it enters clay soils by flowing between the "stacks." The clay plates are held together primarily by calcium ions and to a lesser degree by magnesium ions. Replacement of the calcium ions between the plates with sodium ions tends to force the plates apart and in effect to breakup the "stacks" or "decks."

As the stacks are broken apart, or dispersed, the rate at which water enters the soil (the infiltration rate) decreases. In some cases this rate may become very close to zero. This makes production of crops impractical. This effect does not occur in soils that have no clay and the size of the effect depends on the amount (and type) of clay in the soils. However, almost all of the soils in the Powder and Tongue river basins contain some clay and most of the soils have significant amounts of clay.

In the "Infiltration" portion as shown on Table 1, the restrictions on use are given for various combinations of SAR and EC. These restrictions are actually reductions in infiltration. For instance, if the SAR ranges from 0-3 and the EC is less than 0.2 dS/m (i.e. less than 200 μS/cm) there will be severe reductions in infiltration. If the EC is between 0.2 and 0.7 dS/m there will be slight to moderate reductions in infiltration. If the EC is greater than 0.7 dS/m, there will be no reductions in infiltration. Figure 2 (from Hansen et al.) gives these relationships in a graphical format. It is possible to derive the mathematical relationships of the lines in this figure and the resulting formula can be used to calculate the SAR values that would result in reductions in infiltration at any EC. The mathematical relationship between EC and the SAR that will result in no reduction in infiltration is: SAR = [(EC times 0.0071) - 2.4754] where EC is expressed as μS/cm.

Figure 2.

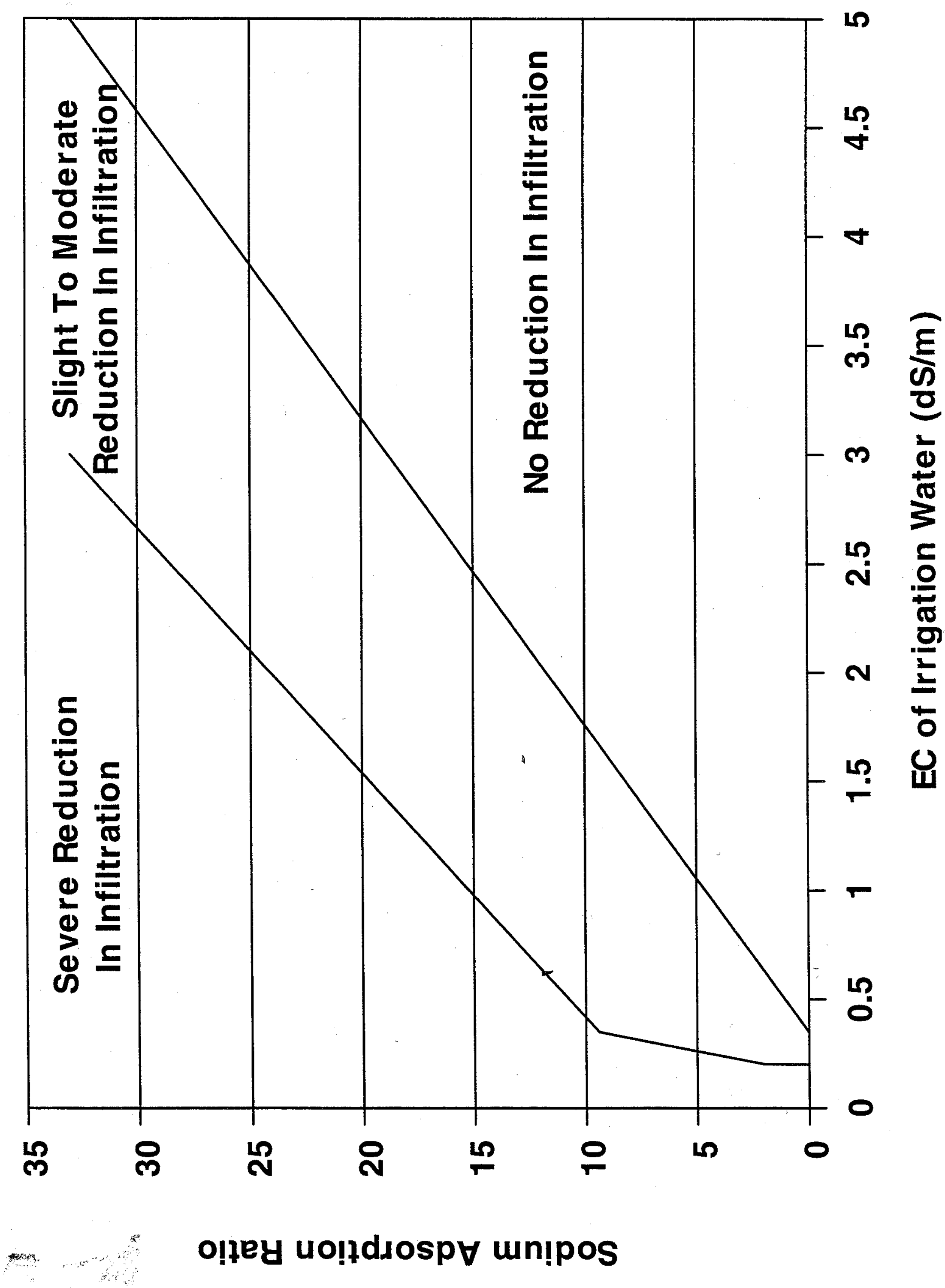

Figure 3. Assessing the effect of salinity and sodium adsorption ratio on infiltration rate.

Based on the considerations given above and given the need to provide an assessment of potential impacts, the SAR value calculated using the formula given above is a reasonable estimate of an effect threshold and is an appropriate benchmark for estimating the potential impact of CBM discharges.

Threshold water quality values to protect riparian plant communities

Approximately 3,500 acres of riparian habitat in Montana are potentially at risk in the CBM development area. Water moving through the alluvium provides water for plant growth in the riparian zone. The sensitivity of native riparian and wetland plants to SAR and salinity is similar to that of irrigated crops. Soils occurring within or along stream channels, flood plains, terraces and alluvial fans in the CBM development area include montmorillonitic clays making these soils susceptible to the effects of SAR. This is significant because water with a high SAR moving through or flooding the alluvium may damage the structure of the soil, impairing the growth of riparian plants. The SAR thresholds necessary to protect the riparian plant community may be different than the SAR thresholds developed to protect irrigation uses because irrigation thresholds apply seasonally while the riparian zone would be continually exposed to water. In addition, in some places the water in the alluvium will tend to "wick" to the surface and evaporate leaving the salts at or near the soil surface. An increase in the salinity of the water may result in increase in the accumulation of salt. Such an increased accumulation could impact the riparian plant communities.

Threshold salinity and SAR values that would protect irrigation uses may or may not protect the riparian plant communities. Because of the lack of data and the site-specific nature of these potential impacts it is not possible to develop specific threshold values for the protection of the riparian plant communities.

Threshold water quality values to protect aquatic species – Bicarbonate Toxicity to Aquatic Life[4]

Mount et al. (1997) described the acute toxicity of major ions to fathead minnows.[5] The relative toxicity of the ions was: potassium (1.0), bicarbonate (0.45), magnesium (0.33), chloride (0.12), sulfate (0.08), sodium (0) and calcium (0). In CBM production water in the Powder River in Wyoming and at the CX Ranch in Montana, sodium bicarbonate is the most prevalent salt. There should be no toxicity associated with the presence of sodium, but the bicarbonate ion is quite lethal to fish.
The toxicity of sodium bicarbonate (as predicted by Mount et al.1997) is shown in Figure 3. To this relationship have been added three lines which describe the relative probability of lethality. The low and high probability lines are positioned at the inflection points on the dose-response curve and correspond to mortality levels of 11 and 89%, respectively. The moderate line corresponds to the level that causes 50% lethality.

The data underlying these probability lines are based on acute (96-hour) toxicity tests with lethality as the end-point, and as noted above, the moderate probability line corresponds to a level that resulted in 50% lethality for the fathead minnows in the Mount et al. toxicity tests (effectively, an LC50 of 1060 mg/l). An allowable "effect threshold" for bicarbonate, however, must ensure an appropriate level of protection for the aquatic community exposed to that pollutant, and clearly a concentration that would allow loss of 50% of, at a minimum, the sensitive fish species within the target aquatic community is not adequately protective.

The application of toxicity data in the derivation of protective aquatic life criteria is addressed by EPA in its aquatic life water quality criteria guidelines.[6] EPA's aquatic life criteria are designed to prevent unacceptable long-term and short-tem effects to a broad range of aquatic organisms. To accomplish this goal, the guidelines establish procedures which derive both acute and chronic criteria based on minimum data-sets which include a range of taxonomic and functional groups. The requirement for a robust data-set as the basis for criteria derivation is to ensure there is reasonable confidence that the national criteria will provide an appropriate level of protection with only a small possibility of considerable overprotection or under-protection.

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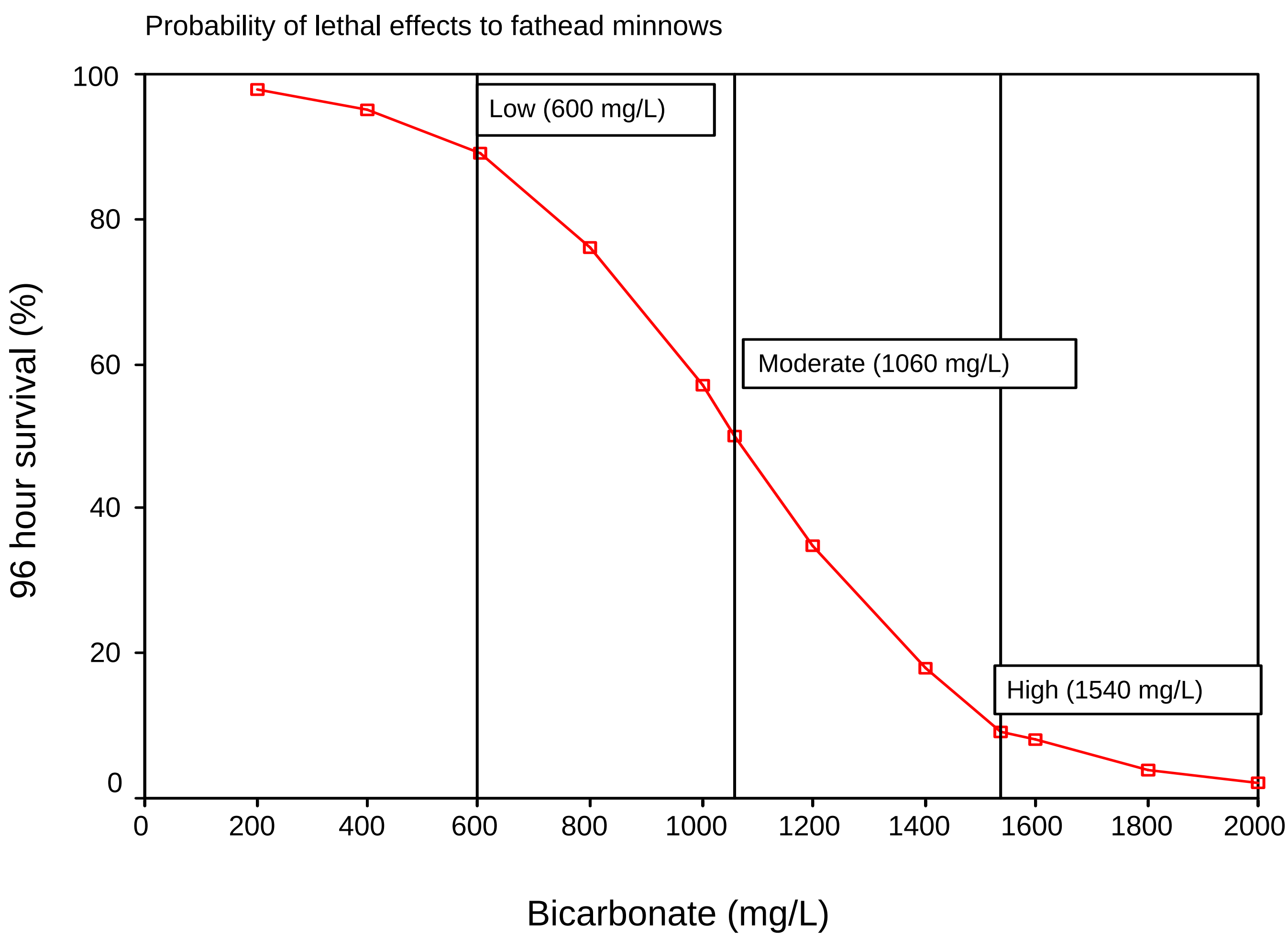
[4]Prepared by Don Skaar, Montana Fish, Wildlife and Parks
[5]Mount, D.R., D.D. Gulley, J.R. Hockett, T.D. Garrison and J.M. Evans. 1997. Statistical models to predict the toxicity of major ions to *Ceriodaphnia dubia, Daphnia magna* and *Pimephales promelas* (fathead minnows). Environmental Toxicology and Chemistry 16 (10): 2009-2019.
[6] Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses, EPA 1985.

Figure 3.



Although the criteria are designed to be appropriately protective in most situations, there likely will be situations where the national criteria are under-protective. These situations are most likely to occur where some untested, locally important species is very sensitive to the pollutant of concern. Further, the criteria derivation process assumes that aquatic ecosystems can tolerate some stress and occasional adverse effects, and therefore, protection of all species at all times and places is not considered to be necessary. As a result, the guidelines assume that a reasonable level of protection will likely be provided if all except a small fraction of the aquatic organisms are protected. The "small fraction" is set at 0.05 for the calculation of a "final acute value." Or, as they are sometimes portrayed, the criteria are designed to protect 95% of the aquatic species (actually, 95th percentile of the species for which there are data). To arrive at an acceptable acute level of protection for the 95th percentile species, the guidelines direct that the final acute value (essentially the LC50 for the 95th percentile species) be divided by 2.

Obviously, the problem presented in estimating an allowable "effect threshold" for bicarbonate, in this situation, is that the protective level is based solely on the short-term survival of one fish species, the sensitivity of which, relative to other fish species is unknown. If however, an assumption is made that the fathead minnow is the 95th percentile species, an appropriate bicarbonate acute-effect threshold, based on EPA's guidelines, would be 1060 mg/l, the LC50 value, divided by 2, or 530 mg/l.

The assumption, that the fathead minnow appropriately represents sensitive fish species for the river basins subject to CBM development, may be conservative, or not. Factors that would argue the assumption and approach are conservative include:

· The 96-hour fathead minnow model, developed in this study, tended to over-predict toxicity to some degree when it was "validated" against samples of water high in salinity.

· The fathead minnows used by Mount et al. were not acclimated to high salinity water. It is possible that, where salinity is already elevated in the streams in question here, the fish resident to these waters would exhibit some level of acclimation to or tolerance for increased levels of salinity. It is also possible that fish native to these waters have developed some genetic adaptation to higher saline waters. On the other hand, the composition of produced waters will most likely not be the same as the waters receiving CBM discharges. And, any acclimation or adaptation of fish to high salinity waters would likely be focused on specific ions, not on salinity generally.

· Actual exposures are unlikely to involve the dramatic changes in water chemistry that fish were subjected to in the laboratory studies.

· Site water may contain constituents that reduce the toxicity of the bicarbonate ion. Two studies conducted by the University of Wyoming suggest that in cases where bicarbonate ions would be expected to convey the majority of lethality to fathead minnows, mortality was far less than would be predicted by the Mount et al. model. These studies used oil-field production water[7] and CBM production water.[8]

Factors that would argue the assumption and approach are not conservative include:

[7] Boelter, A.M., F.N. Lamming, A.M. Farag, and H.L. Bergman. 1992. Environmental effects of saline oil-field discharges on surface waters. Environmental Toxicology and Chemistry 11: 1187-1195.

[8] Forbes, M.B., S.J. Clearwater, and J.S. Meyer. 2001. Acute toxicity of coalbed methane product water and receiving waters to fathead minnows (*Pimephales promelas*) and *Daphnia magna*. University of Wyoming. 4 pp plus appendices. Prepared for the Wyoming Department of Environmental Quality.

- The end point is lethality of post-hatch fish; only an acute effect threshold is calculated, and there is no accounting for chronic toxicity. In addition, it is not known if the post-hatch stage is the most sensitive. The egg stage has been shown to be quite sensitive to salts.[9,10,11]

- The fathead minnow may not be the fish species most sensitive to the toxic effects of bicarbonate. If some untested, locally important species is very sensitive to bicarbonate, the fathead minnow assumption leads to an under-protective effect threshold. This is an especially important consideration given the State's fish species of special concern that occur in the river basins within the CBM development area.

- There is no consideration of invertebrate sensitivity. Available information for certain daphnid species indicates they are more sensitive to bicarbonate toxicity than are fathead minnows. [5,7,12] Therefore, even if the fathead minnow appropriately represents the sensitivity of fish to bicarbonate toxicity, it is uncertain that the derived effect threshold would be adequately protective of the aquatic invertebrate communities in streams receiving CBM discharges.

- There is no accounting for the toxic effects of other ions that are already present in these streams, particularly sulfates. Because the Mount model assumes that the toxic effects of major ions are additive, the presence of the other ions in receiving waters will convey some lethality to fish. Therefore, an effect threshold based solely on bicarbonate is likely to be underprotective.

Taking all of the above into consideration and given the need to provide an assessment of potential impacts, MFWP and MDEQ believe a bicarbonate value of 530 mg/l is a reasonable estimate of an effect threshold and would adequately serve as an appropriate benchmark for estimating the potential impact of CBM discharges of bicarbonate. MFWP and MDEQ, therefore, recommend that a bicarbonate level of 530 mg/l be used in evaluating the potential impact of CBM bicarbonate discharges to aquatic resources in the Tongue, Powder, Little Powder and Little Big Horn River Basins and Rosebud Creek .

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[9] Koel,T.M. and J.J. Peterka. 1995. Survival to hatching of fishes in sulfate-saline waters, Devels Lake, North Dakota. Can. J. Fish. Aquat. Sci. 52:464-469.

[10] Burnham, B.L. and J.J. Peterka. 1975. Effects of saline water from North Dakota lakes on survival of fathead minnow *(Pimephales promelas*) embryos and sac fry. J. Fish. Res. Bd. Can. 32:809-812.

[11] Mossier, J.N. 1971. The effect of salinity on the eggs and sac fry of the fathead minnow (*Pimephales promelas promelas*), northern pike (*Esox lucius*), and walleye (*Stizostedion vitreum vitreum*). PhD thesis, North Dakota State University, Fargo, 47 pp.

Evaluation of the Impacts of CBM Discharges on Streams in the Powder River Basin using Irrigation Thresholds[12]

This section of the report evaluates the cumulative water quality resulting from discharge of untreated CBM produced water to streams in the PRB. The analysis is based upon estimates of the number of potential new CBM wells, which is described by the Bureau of Land Management (BLM) as the “Reasonably Foreseeable Development" (RFD). Projections of RFD of CBM in both Wyoming and Montana have been the subject of recent BLM reports. This technical report uses identical estimates of RFD now being analyzed by BLM in Wyoming and Montana as part of the analysis under the National Environmental Policy Act (NEPA). For the next 20 years, BLM estimates that there could be an RFD of approximately 31,200 new wells in the Wyoming portion of the PRB and approximately 24,800 new wells in Montana’s portion of the basin. These estimates are distributed among the analyzed watersheds as shown in Table 3.

Table 3.
Estimated Maximum Potential Number of CBM Wells in the Powder River Basin, Wyoming and Montana.

Watershed	Number of RFD CBM Wells
Wyoming	
Little Powder River ab Dry Creek nr Weston and above	2035
Powder River at Moorhead and above	26598
Tongue River at State Line nr Decker and above	2589
Montana	
Little Powder River near Broadus	278
Powder River at Broadus	3167
Mizpah Creek near Mizpah	224
Tongue River at State Line nr Decker	2903
Tongue R at Birney Day School nr Birney	2903
Tongue R bl Brandenberg Bridge nr Ashland	2592
Tongue River at Miles City	2592
Rosebud C at Reservation Bndry nr Kirby	1799
Rosebud Creek near Colstrip	1799
Rosebud Creek at Mouth near Rosebud	1799
Little Bighorn R bl Pass Cr nr Wyola	525
Little Bighorn River near Hardin	525
Lower Bighorn River near ST. Xavier	600
Lower Bighorn River ab Tullock Cr nr Bighorn	600

The following sections summarize the flow and water quality data available for streams and CBM produced water in both the Wyoming and Montana portions of the PRB. This information is used to develop a representative set of flow and water quality values, which together with the irrigation and aquatic life thresholds described in previous sections, form the basis of the subsequent impact analyses.

[12] Prepared by Helen Dawson, EPA Region 8.

Following presentation of the available data, three scenarios are evaluated for this impact analysis: (1) a scenario corresponding to the assumptions used in the Draft EIS, (2) a scenario using moderate assumptions, and (3) a case with restrictive assumptions.

Powder River Basin Surface Water Characteristics

Stream Flow

Representative flow rates for streams in the PRB were determined from analysis of the historical record at USGS flow monitoring stations (Table 4). Base-flow conditions in the streams are represented by the low of the mean monthly flows in the streams and typically occur in the winter months. These values also are representative of low flow conditions during the irrigation season spanning March through September. The median of the mean monthly flows for each watershed, also listed in the table, is used to represent a characteristic monthly flow for the stream. The median mean monthly flows are used in the moderate-case impact analysis and the low mean monthly flows are used in the restrictive-case impact analysis and Draft EIS impact analysis.

Table 4.
Stream Flow Statistics for Selected Watersheds in the Powder River Basin.

Watershed	Period of Record	Low Mean Monthly Flow (cfs)	Irrigation Season Low Mean Monthly Flow (cfs)	Median Mean Monthly Flow (cfs)
Little Powder River ab Dry Creek nr Weston	1972-2000	3	4	12
Little Powder River near Broadus	1978-2000	4	7	21
Powder River at Moorhead	1929-2000	149	149	260
Powder River at Broadus	1975-1992	173	173	256
Tongue River at State Line nr Decker	1960-2000	180	182	246
Tongue R at Birney Day School nr Birney	1979-2000	185	236	272
Tongue R bl Brandenberg Bridge nr Ashland	1974-2000	207	321	330
Tongue River at Miles City	1938-2000	188	188	274
Rosebud C at Reservation Bndry nr Kirby	1979-2000	2	2	4
Rosebud Creek near Colstrip	1974-2000	8	8	18
Rosebud Creek at Mouth near Rosebud	1974-2000	9	9	20
Little Bighorn R bl Pass Cr nr Wyola	1939-2000	105	111	121
Little Bighorn River near Hardin	1953-2000	123	123	183
Lower Bighorn River near ST. Xavier	1934-2000	2612	2759	2936
Lower Bighorn River ab Tullock Cr nr Bighorn	1945-2000	2884	2884	3325
Mizpah Creek near Mizpah	1974-1986	0.3	2	11

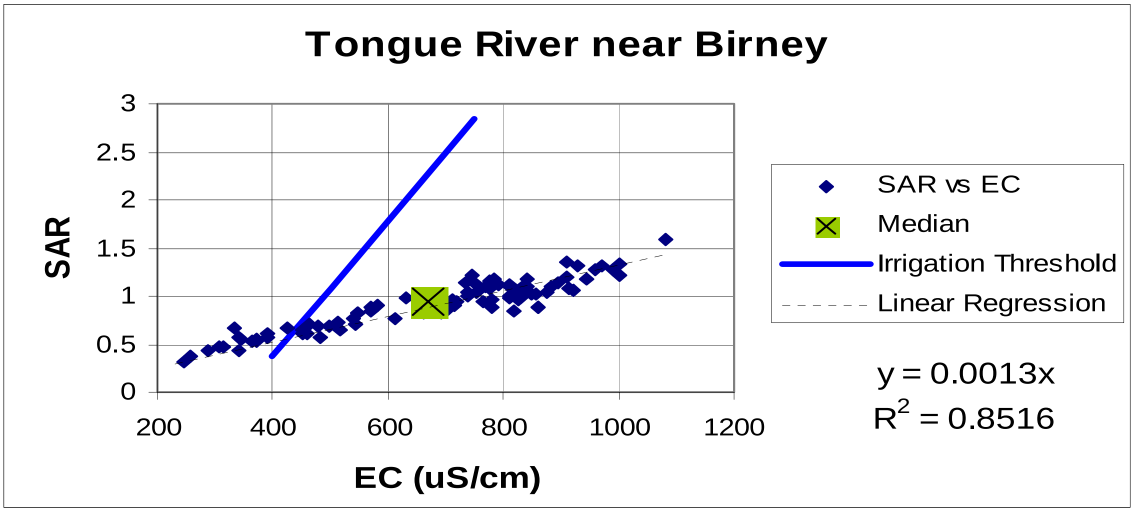
Surface Water Quality

Because irrigation is a significant use of surface water in the Montana portion of the PRB baseline water quality parameters such as EC and SAR are important to consider in evaluating the impact of CBM water discharge on surface water quality. Representative values of EC and SAR were determined from the historical record at USGS monitoring stations (Table 5). Plots of SAR versus EC demonstrate there is a positive correlation between EC and SAR for most streams (except the Little Powder River). Stream waters high in EC typically have high SAR values. Figure 4 shows an example of the relationship between EC and SAR and the corresponding linear regression. Representative EC and SAR values should fall within these correlated distributions. The average values are used in the Draft EIS analysis and the median values are used in the moderate and restrictive-case impact analyses.

Table 5.
EC and SAR for Selected Watersheds in the Powder River Basin.

Watershed	Period of Record	Median EC (uS/cm)	Average EC (uS/cm)	N	Median SAR	Average SAR	N
Little Powder River ab Dry Creek nr Weston	1979-1999	2890	2890	178	5.5	5.5	197
Little Powder River near Broadus	1978-2001	2110	2110	16	9.4	9.4	16
Powder River at Moorhead	1969-1999	1950	1950	264	4.5	4.5	154
Powder River at Broadus	1978-1989	2025	2052	62	4.7	4.7	13
Mizpah Creek near Mizpah	1975	1980	1980	104	11	13	73
Tongue River at State Line nr Decker	1985-1999	610	673	115	0.56	0.67	25
Tongue R at Birney Day School nr Birney	1979-1999	670	719	153	0.87	0.94	93
Tongue R bl Brandenberg Bridge nr Ashland	1974-2001	818	871	113	1.6	1.8	87
Tongue River at Miles City	1959-1999	840	840	548	1.5	1.5	408
Rosebud C at Reservation Bndry nr Kirby	1979-1999	950	942	149	0.7	0.7	41
Rosebud Creek near Colstrip	1974-1999	1380	1376	190	1.5	1.4	95
Rosebud Creek at Mouth near Rosebud	1974-1999	1590	1720	223	3.1	3.1	16
Little Bighorn R bl Pass Cr nr Wyola	1993-1999	452	453	44	0.2	0.2	16
Little Bighorn River near Hardin	1969-1999	712	723	368	1.22	1.1	212
Lower Bighorn River near ST. Xavier	1966-1999	847	837	388	2.0	2.0	223
Lower Bighorn River ab Tullock Cr nr Bighorn	1959-1999	935	953	525	2.1	2.2	73

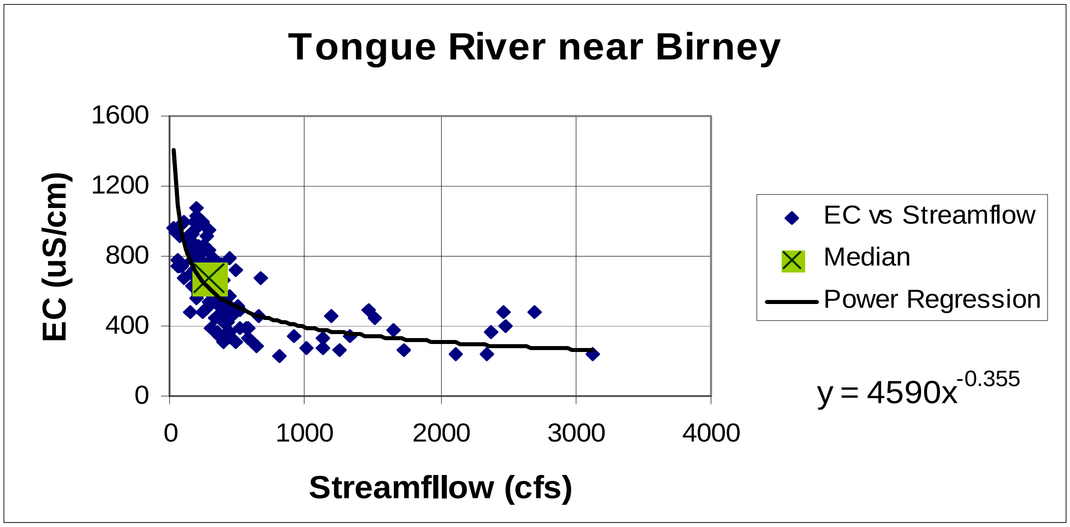
Figure 4. Relationship between SAR and EC in the Tongue River near Birney.



Stream Flow - Water Quality Relationships

Water quality in most watersheds varies inversely with flow rate. Both EC and SAR tend to be elevated during low flow periods. The exception is the Little Powder River, which does not show any correlation between EC or SAR and flow rate. Figure 5 shows an example of the correlation typically observed, with a power function fit to the data. The median of the mean monthly flow rates and median EC values fall within these distributions. The fitted power curve can be used to estimate water quality parameters, in this case EC, corresponding to a given flow rate.

Figure 5. Relationship between EC and flow in the Tongue River near Birney.



CBM Water Quality and Discharge Rates

Water Quality

CBM produced water quality (EC and SAR) is summarized in Table 6 and Figure 6, which plots mean SAR versus mean EC values for CBM water produced in the Little Powder, Powder and Tongue River drainages. For comparison, also shown in the figure is the line representing SAR/EC thresholds below which there is no restriction for irrigation. The ovals centered on the means represent the range of the data. The Tongue River statistics were determined from 55 water quality analyses of CBM produced water. The summary statistics for the Little Powder and Powder River drainages were obtained from a report by O & G Environmental Consulting [13] which summarize the results of 1256 water samples in the Powder River watershed and 784 water samples in the Little Powder River watershed. Mean EC and SAR values for CBM water are used in both the moderate and restrictive impact analyses.

[13] O & G Environmental Consulting, "Coal Bed Methane Operators Information Survey Results," September 7, 2001.

Table 6.
Water Quality Parameters for CBM Produced Water.

Watershed	EC			SAR			
	Mean	Low	High	Mean	Low	High	Source
Little Powder River	1655	1647	1662	15.4	10.7	20.1	O&G Sep 2001
Powder River	2735	1750	3440	22.3	14.7	29.7	O&G Sep 2001
Tongue River	2207	1473	3131	40	9	60	Fidelity Exploration

Figure 6. CBM water quality in the Powder River Basin.

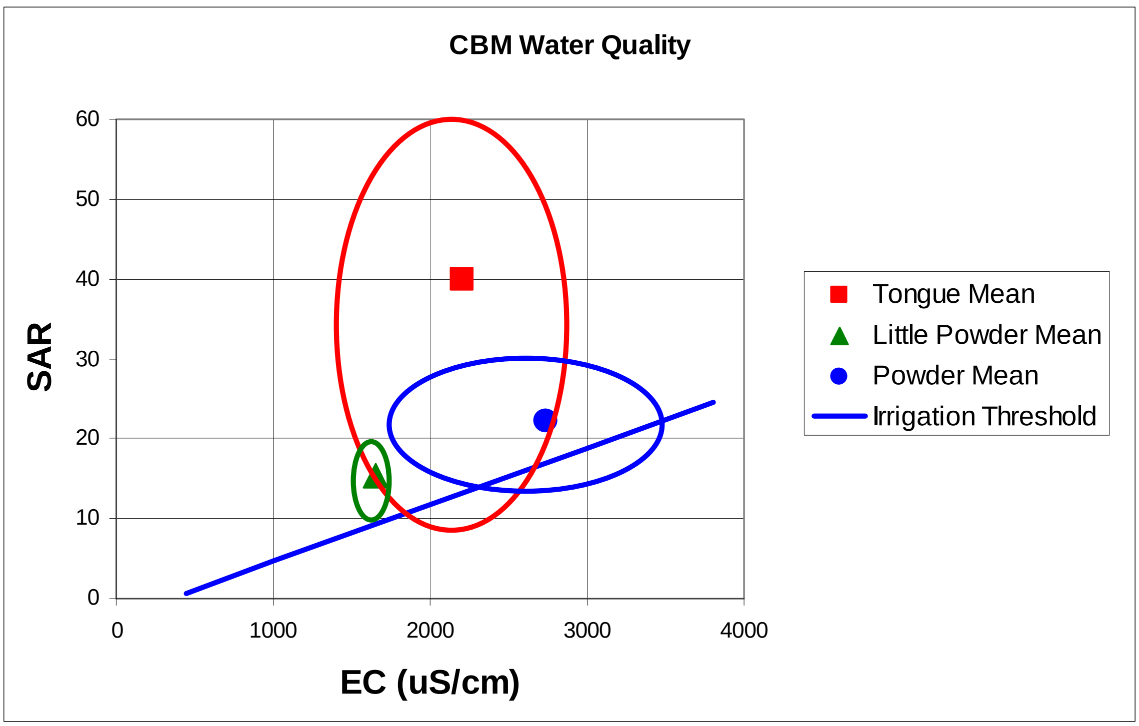


Figure 6 shows that there is considerable overlap between CBM produced water in the PRB. Other data not shown here indicate there is general increase in mean SAR levels from south to north within the PRB. It is not known whether this general increase continues to the northernmost drainages of the PRB. Overall, SAR values range over an order of magnitude, whereas EC values vary only by a factor of two or three. Plots of individual water quality analyses indicate there is no apparent correspondence between SAR and EC values among individual samples of CBM produced water.

CBM produced waters on average exhibit higher SAR and EC levels than most streams in the PRB. In the Little Powder River drainage, however, CBM produced water EC is lower than the stream's EC, except during high flows. Consequently, discharge of CBM produced water could improve the salinity of the Little Powder River.

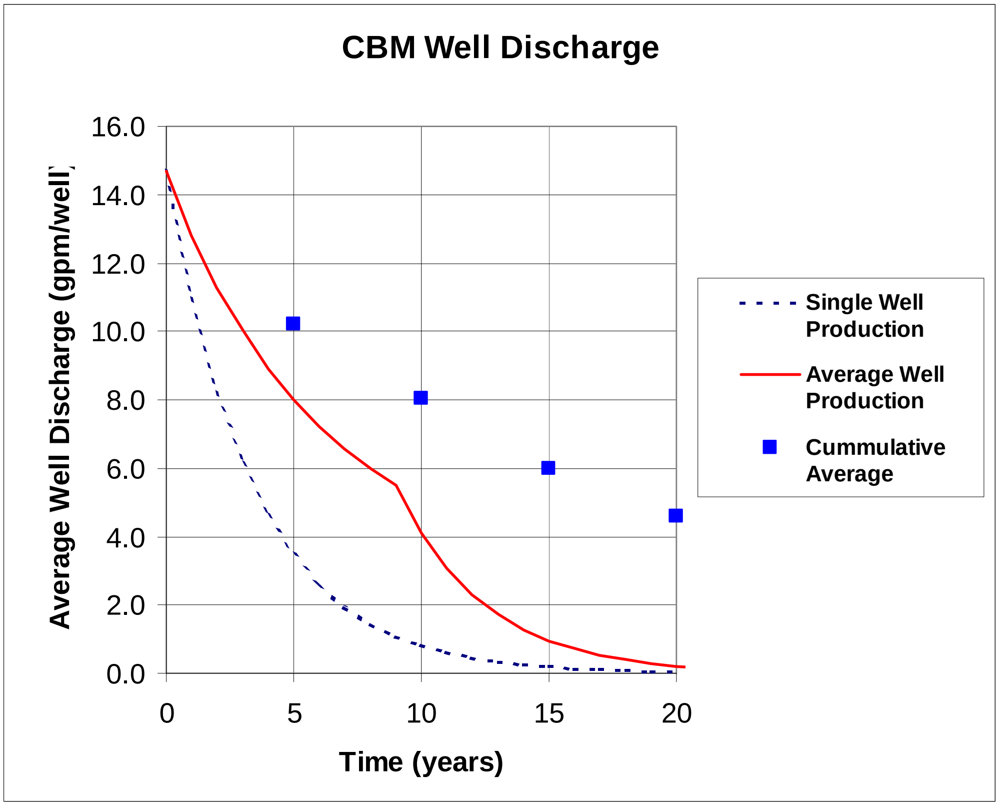
In assessing the impact of CBM produced water on surface water quality in the PRB, it is important to consider changes in water quality that may occur as the CBM discharge flows overland toward the mainstem streams. Water quality and flow monitoring results for tributaries to the Powder and Little Powder Rivers suggest that CBM discharges tend to pick up salts (increase in EC) from the soils and alluvium as they flow down tributary channels and that SAR levels decline as CBM discharge flows down these tributary channels. For example, a tributary monitoring program conducted in Wyoming found that the flow weighted average EC of Powder River tributaries is 4192 μS/cm, as compared to an average EC of 2300 μS/cm for CBM discharges in the drainage. The flow weighted SAR value for tributaries in the Powder River drainages was 12, as compared to an average SAR of 17 for CBM discharges in the drainage[14]. These changes suggest that between the discharge point and the receiving streams, CBM water quality may improve with respect to SAR but worsen with respect to EC. While improvements in water quality may occur in other drainages in the PRB, using the discharged CBM water quality provides a more conservative estimate of the impact of CBM water on surface water quality, particularly since SAR varies considerably more than EC in CBM produced water.

Discharge Rate

The rate of water production from CBM wells typically is high initially and declines with time. For example, water production rates from CBM wells in the Powder River and Little Powder River drainages in Wyoming averaged approximately 12 gpm/well in 1997 and declined to an average of approximately 7 gpm/well in the first eight months of 2001. The cumulative average over this five-year period is reported to be approximately 10 gpm/well[15]. In the CX Ranch project, water production rate for an individual well was observed to decline from approximately 15 gpm to 8 gpm over two years. If the rate of production from this individual CX Ranch well is considered representative of all potentially producing CBM wells in Montana, the projected production rate of this well can be used to estimate the average production rates of a field of wells. This is illustrated in Figure 7. The development of CBM wells is likely to be staggered, with new wells producing at an initially high rate coming on each year while in older wells the production rate declines. Assuming approximately 10 percent of the RFD number of wells come on line in any one year, the estimated five year average water production rate is approximately 10 gpm/well, similar to the five-year average observed in Wyoming. The subsequent 10-year, 15-year and 20-year averages are estimated to be 8, 6 and 5 gpm/well, respectively. These values are roughly double the values calculated for a single well. The 20-year average is used in the moderate-case impact analysis and the five-year average is used in the restrictive-case impact analysis.

[14]Applied Hydrology Associates, "Cumulative Impacts of Coal Bed Methane Development on Water Quality in the Powder and Little Powder Rivers," August 16, 2001.
[15] Wyoming Oil and Gas Conservation Commission, Coal Bed Methane Report, Presented August 20, 2001.

Figure 7. Hypothetical produced water discharge rate from a CBM well-field.



<u>Conveyance loss</u>

In assessing the impact of CBM produced water on surface water quality in the PRB, it is also important to consider losses in quantity of water that may occur between the discharge point and the receiving streams. As the CBM water flows overland toward the mainstem streams, some water is likely to infiltrate into the soil and some will evaporate. This conveyance loss was estimated to be as high as 90 to 95% in the Belle Fourche area[16]. However, this study used weirs to reduce overland flow rates, which would serve to increase ponding and consequently increase infiltration and evaporation. Lower conveyance losses are likely to be observed in cold seasons, when evaporation decreases and where discharge is directed to stream channels. In the latter case, CBM discharge may continue to flow through subsurface sediments and consequently reach the mainstem streams.

[16] Applied Hydrology Associates, "Cumulative Impacts of Coal Bed Methane Development on Water Quality in the Powder and Little Powder Rivers," August 16, 2001.

Infiltration into soil in arid areas typically comprises approximately 20 percent of precipitation in a watershed[17]. Assuming this value represents the minimum loss in overland flow yields a restrictive-case estimate of 20% conveyance loss. Assuming no water is used for beneficial purposes results in delivery to the mainstem stream of 80% of the CBM water produced. These values are used in the restrictive-case impact analysis. However, because of potential ponding in the stream channels, infiltration losses may be higher. Higher infiltration rates combined with some evaporative losses and beneficial use of the produced water results in a smaller fraction delivered to the mainstem streams. The moderate-case impact analysis assumes 10% beneficial use and then a 50% conveyance loss resulting in delivery to the mainstem streams of 45% of the CBM water produced.

Conveyance loss is a controllable variable in that management practices, such as locating discharge points further up tributary drainages or near the divide and construction of reservoirs for containment of water, can be employed to increase conveyance loss. Thus, optimization of CBM development may be accomplished by using engineered controls to increase conveyance losses.

Impact Analysis Assumptions

The following analyses all assume that all CBM production water is discharged continuously and that there is no storage or treatment. Because, the thresholds to protect irrigation apply only during the irrigation season this assumption results in an underestimate of the number of wells that could discharge without exceeding the thresholds.

Draft EIS Assumptions[18]

- CBM discharge rate: 2.5 gpm/well (single well 20-year average)
- Beneficial Use: 20%
- Conveyance Loss: 70%
- Effective discharge to rivers: 24%
- CBM water quality: EC of 2207 μS/cm (mean of CX ranch CBM produced water); SAR of 47 as stated in Draft EIS; same values were used for all drainages
- Stream flow rates: low mean monthly flow rates as shown in Table 4
- Stream water quality: low flow EC and SAR as shown in Table 5

[17] Stephens, D.B. and Knowlton, R. Jr., “Soil Water Movement and Recharge Through Sand at a Semiarid Site in New Mexico,” Water Resources Research, Vol. 22, No. 6, p 881-889, June 1986.
[18] ALL Consulting, “Water Resources Technical Report,” June 2001.

- EC and SAR limits: based on no reduction in infiltration EC-SAR relationship; further limited by suggested MT DEQ thresholds (high level): SAR <= 12 for the Powder, Little Powder and Mizpah Rivers, SAR <= 2 or 12 for all other streams

- Cumulative Impacts from Upstream Development: All upstream development including development in Wyoming is evaluated for each watershed. If multiple stream gauge locations occur in a watershed, the projected number of wells is divided equally among the reaches represented by the stations.

- Allocation factors: 50/50 between Wyoming and Montana

<u>Moderate-case assumptions</u>

- CBM discharge rate: 5 gpm/well (multiple-well 20-year average)

- Beneficial Use: 10%

- Conveyance Loss: 50%

- Effective discharge to rivers: 45%

- CBM water quality: mean EC and SAR for each drainage as shown in Table 6

- Stream flow rates: median of mean monthly flow rates as shown in Table 4

- Stream water quality: median EC and SAR values as shown in Table 5

- EC and SAR limits: based on no reduction in infiltration EC-SAR relationship; further limited by suggested MT DEQ thresholds (high level): EC <= 2200 μS/cm for the Powder, Little Powder and Mizpah Rivers, EC <= 1000 for all other streams; SAR <=12

- Cumulative Impacts from Upstream Development: All upstream development including development in Wyoming is evaluated for each watershed. If multiple stream gauge locations occur in a watershed, the projected number of wells is divided equally among the reaches represented by the stations.

- Allocation factors: 50/50 between Wyoming and Montana

<u>Restrictive-Case Analysis Assumptions</u>

- CBM discharge rate: 10 gpm/well (multiple-well 5-year average)

- Beneficial Use: 0%

- Conveyance Loss: 20%
- Effective discharge to rivers 80%
- CBM water quality: mean EC and SAR for each drainage as shown in Table 6
- Stream flow rates: median of mean monthly flow rates as shown in Table 4
- Stream water quality: median EC and SAR values as shown in Table 5
- EC and SAR limits: based on no reduction in infiltration EC-SAR relationship; further limited by suggested MT DEQ thresholds (low level): EC <= 1600 µS/cm for the Powder, Little Powder and Mizpah Rivers, EC <= 750 for all other streams; SAR <=12 cm for the Powder, Little Powder and Mizpah Rivers, SAR <= 2 for all other streams
- Cumulative Impacts from Upstream Development: All upstream development including development in Wyoming is evaluated for each watershed. If multiple stream gauge locations occur in a watershed, the projected number of wells is divided equally among the reaches represented by the stations.
- Allocation factors: 50/50 between Wyoming and Montana

Model Description

Completely mixed mass balance model

The model employed in this impact analysis uses a mass balance approach to estimate steady state concentrations of conservative (non-reactive) constituents after two or more inflows are mixed.

Model peer review

The model has been peer reviewed by Bruce Zander, EPA Region VIII TMDL Coordinator. His findings are summarized below and the memo describing his assessment is available upon request.

> The internal calculations of SAR and EC in the model are based on a mass balance approach. The steady state mass balance approach is commonly used by EPA Region VIII states in predicting effects of point source discharges on receiving waters. It has been a common approach endorsed in EPA guidance through the years (e.g., see "Technical Support Document for Water Quality-based Toxics Control", March 1991).
>
> All aspects of the model, including the mathematical logic, the assumptions, and the relative sensitivities of the variables were reasonable in their basis and construction. This model provides an appropriate tool to predict effects on proposed development within the watersheds of concern.

Model verification

A verification data set has been developed from USGS stream gauging stations on the Powder River and its tributaries. The model was found to adequately predict measured downstream concentrations of SAR resulting from mixing of mainstem water with tributary water.

Impact Analysis Results and Conclusions

Draft EIS Impact Analysis

The impact of untreated CBM discharge on surface water quality in PRB streams in Montana was analyzed using the set of assumptions developed in the Draft EIS as described above. This impact analysis, summarized in Table 7 and Figure 8, is based on the assumption that CBM wells produce water at an average rate of 2.5 gpm/well with discharge reduced by 20% due to beneficial use and additionally by 70% due to conveyance loss. The effective discharge to streams is 24% of the amount of water produced. A SAR value of 47 and EC value of 2207 µS/cm was used for all streams. Base stream flow rates—equal to the low mean monthly flows—were input, along with average values of EC and SAR for baseline stream water quality. All upstream development, including development in Wyoming, was evaluated for each watershed.

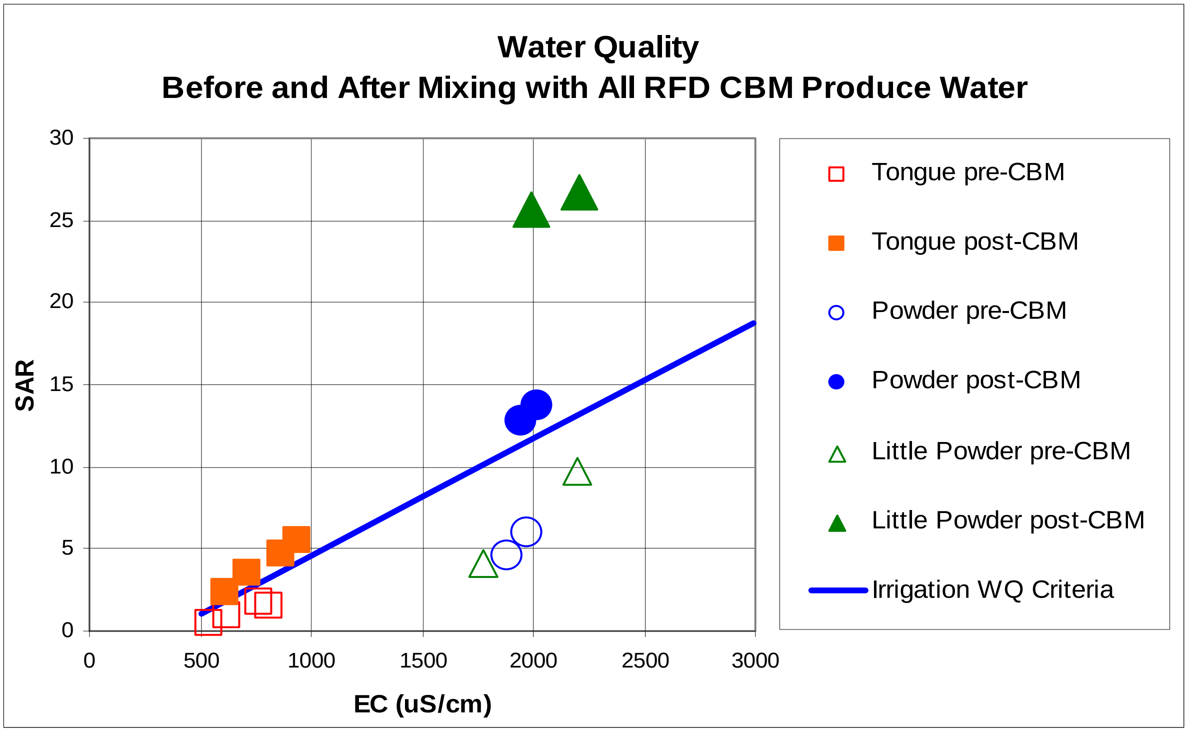
Figure 8 shows that the discharge of untreated CBM produced water to streams will render all rivers, except the Bighorn and Little Bighorn Rivers, unusable for irrigation based on the EC-SAR relationship that represents no reduction in infiltration. The Bighorn and Little Bighorn Rivers also meet the additional limitation on SAR (<=12) proposed in the Draft EIS; the SAR values in these rivers after mixing with the RFD CBM discharge are less than 12. If the SAR criterion is 2 instead of 12, then only the Little Bighorn River would maintain acceptable water quality after mixing with the RFD CBM discharge (SAR < =2).

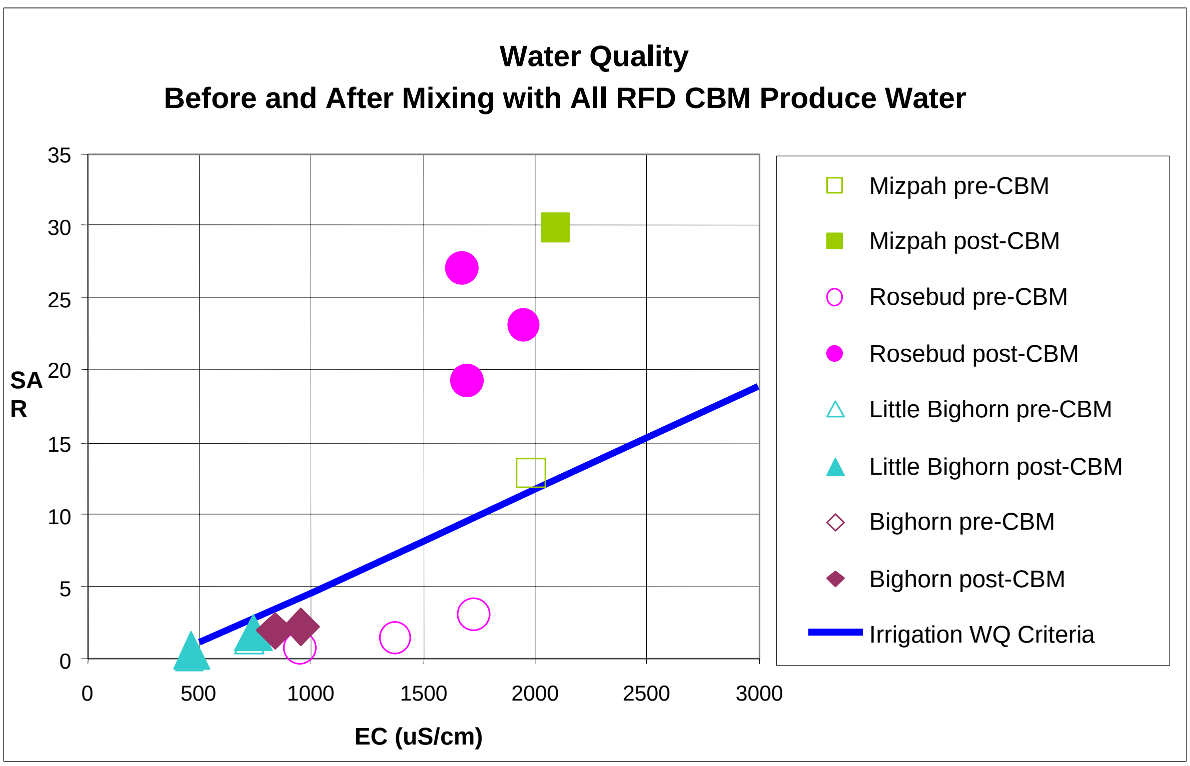
Table 7.
Summary of Draft EIS Impact Analysis.
Based on Thresholds[1] for Irrigation in MT.

Location	Impact to Irrigation (EC and SAR Exceed Threshold)	Impact to Aquatic Life (HCO3 Exceeds Threshold)
Little Powder River ab Dry Creek nr Weston	Adverse	
Little Powder River nr Broadus	Adverse	
Powder River at Moorhead	Adverse	
Powder River at Broadus	Adverse	
Mizpah Creek nr Mizpah	Adverse	
Tongue River at State Line nr Decker	Adverse	
Tongue R at Birney Day School Br nr Birney	Adverse	
Tongue R bl Brandenberg Bridge nr Ashland	Adverse	
Tongue River at Miles City	Adverse	
Rosebud C at Reservation Bndry nr Kirby	Adverse	
Rosebud Creek nr Colstrip	Adverse	
Rosebud Creek at Mouth near Rosebud	Adverse	
Little Bighorn R bl Pass Cr nr Wyola	None	
Little Bighorn River near Hardin	None	
Lower Bighorn River near ST. Xavier	None	
Lower Bighorn River ab Tullock Cr nr Bighorn	None	

[1] Based on SAR threshold of 12

Figure 8. Draft EIS impact analysis. Water quality of PRB streams before and after mixing with RFD CBM discharge.





To ensure that irrigation thresholds are met, discharge of CBM produced water needs to be limited and, consequently, the number of wells that can discharge untreated water directly to the mainstem streams needs to be limited. This analysis uses the EC-SAR relationship and a cap of 12 on SAR to calculate the maximum allowable discharge and, based on the effective discharge rate, the maximum number of allowable discharging CBM wells. Additionally, the assimilative capacity at the stateline stations was split equally between Wyoming and Montana. The calculated limits on CBM discharge and number of CBM wells are listed in Table 8. Discharge of untreated CBM produced water needs to be restricted to 20% to 60% of the RFD projected amount for the Tongue, 8% to 46% in Rosebud, and less than 33% in the Little Powder River in Montana. On the Wyoming side, discharge needs to be restricted to less than 4% in the Little Powder, 40% in the Powder, and less than 70% in the Tongue. The limits vary due to differences in baseline water quality in the reaches of the streams, which results in differences in the assimilative capacity of each reach. These results are based on the assumption that the quality of CBM produced water is the same throughout the PRB and is represented by the water quality of the CBM wells at the CX Ranch on the Tongue River. If water quality parameters representative of the CBM water produced in the Little Powder and Powder Rivers are used as input to the model rather than the CX Ranch values used in the Draft EIS, the amount of CBM produced water that can be released to the Little Powder and Powder Rivers is greatly increased. If SAR is limited to 2 instead of 12 for all rivers except the Little Powder and Powder, very little CBM discharge can be accommodated in the rivers (Table 9). The allowable discharge in the Tongue would decrease to a fifth of that allowed with a SAR cap of 12 and no discharge of untreated CBM produced water would be allowed in either the Rosebud or Lower Bighorn drainages.

Table 8.
Limits on CBM Discharge and Number of Discharging CBM Wells to Avoid Exceeding Irrigation Thresholds for Irrigation in Montana.
Draft EIS Impact Analysis with a SAR cap of 12.

Location	Discharge Limit (cfs)	Number of CBM Wells	Fraction of RFD CBM Wells (%)
Wyoming			
Little Powder River ab Dry Creek nr Weston	0.1	91	4
Powder River at Moorhead	13.9	10356	39
Tongue River at State Line nr Decker	2.4	1793	69
Montana			
Little Powder River nr Broadus	0.1	91	33
Powder River at Broadus	14.5	RFD (3167)	100
Mizpah Creek nr Mizpah	0	0	0
Tongue River at State Line nr Decker	2.4	1793	62
Tongue R at Birney Day School Br nr Birney	0.8	598	21
Tongue R bl Brandenberg Bridge nr Ashland	2.1	1588	61
Tongue River at Miles City	2.1	1602	62
Rosebud C at Reservation Bndry nr Kirby	0.2	141	8
Rosebud Creek near Colstrip	1.1	834	46
Rosebud Creek at Mouth nr Rosebud	0.4	285	16
Little Bighorn R bl Pass Cr nr Wyola	1.5	RFD (525)	100
Little Bighorn River nr Hardin	3.4	RFD (525)	100
Lower Bighorn River nr ST. Xavier	106.1	RFD (600)	100
Lower Bighorn River ab Tullock Cr nr Bighorn	63.2	RFD (600)	100

Table 9
Limits on CBM Discharge and Number of Discharging CBM Wells to Avoid Exceeding Irrigation Thresholds for Irrigation in Montana.
Draft EIS Impact Analysis with SAR Cap of 2 for the Tongue River and Rosebud Creek.

Location	Discharge Limit (cfs)	Number of CBM Wells	Fraction of RFD CBM Wells
Wyoming			
Little Powder River ab Dry Creek nr Weston	0.1	91	4
Powder River at Moorhead	13.9	10356	39
Tongue River at State Line nr Decker	2.4	1793	69
Montana			
Little Powder River nr Broadus	0.1	91	33
Powder River at Broadus	RFD	RFD (3167)	100
Mizpah Creek nr Mizpah	0	0	0
Tongue River at State Line nr Decker	0.7	516	18
Tongue R at Birney Day School Br nr Birney	0.0	0	0
Tongue R bl Brandenberg Bridge nr Ashland	0.0	0	0
Tongue River at Miles City	0.7	530	20
Rosebud C at Reservation Bndry nr Kirby	0.0	0	0
Rosebud Creek near Colstrip	0.0	0	0
Rosebud Creek at Mouth nr Rosebud	0.0	0	0
Little Bighorn R bl Pass Cr nr Wyola	RFD	RFD(525)	100
Little Bighorn River nr Hardin	RFD	RFD (525)	100
Lower Bighorn River nr ST. Xavier	0.0	0	0
Lower Bighorn River ab Tullock Cr nr Bighorn	0.0	0	0

Moderate -Case Impact Analysis

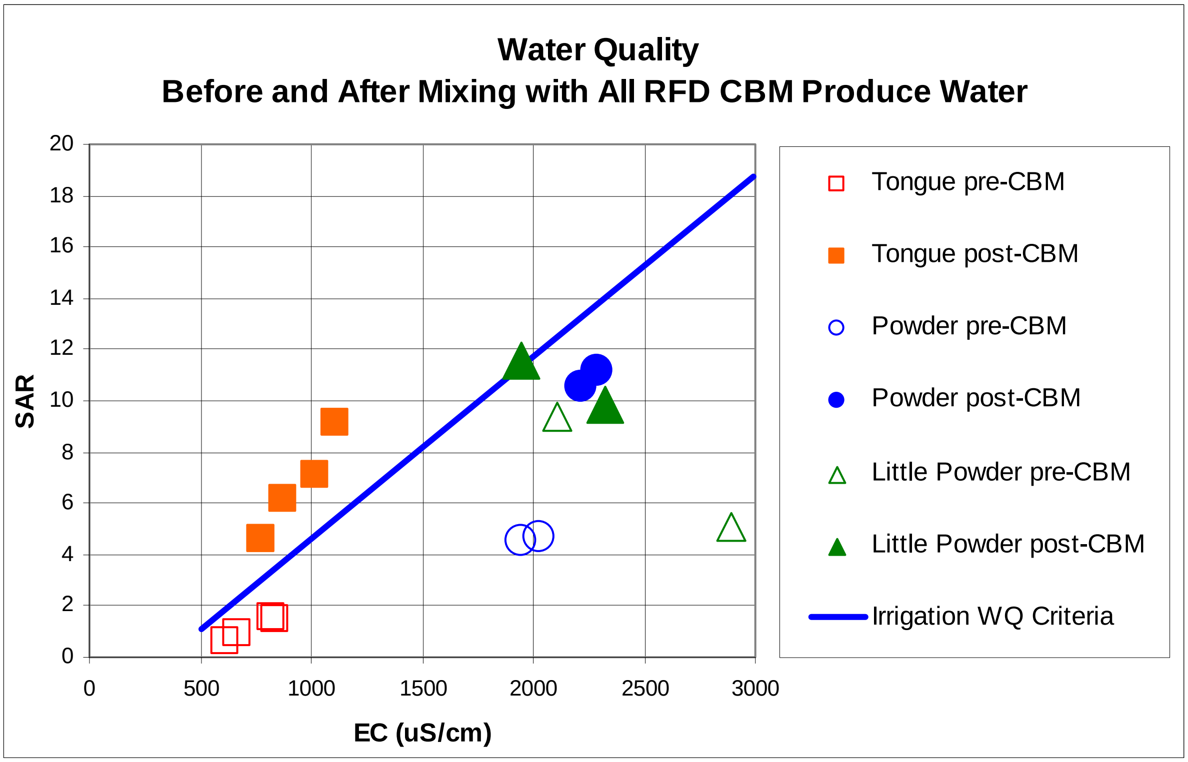
The moderate-case impact analysis of CBM produced water discharge on surface water quality in PRB streams in Montana is summarized in Table 10 and shown in Figure 9. This analysis is based on the assumptions that CBM wells produced water at an average rate of 5 gpm/well over 20 years with discharge reduced by 10% due to beneficial use and additionally by 50% due to conveyance loss. The effective discharge to streams is 45% of the amount produced. A mean SAR of 40 and mean EC of 2207 µS/cm were used to represent CBM produced water quality in the Tongue River drainage and all other watersheds to the north of the Tongue. For CBM discharges in the Little Powder River drainages, the mean SAR and EC values used were 15 and 1655 µS/cm, respectively. For the Powder River drainages, the mean CBM discharge SAR and EC values used were 22 and 2735 µS/cm, respectively. Median flow rates, along with median values of EC and corresponding SAR values were used to characterize the streams. All upstream development, including development in Wyoming, was evaluated for each watershed.

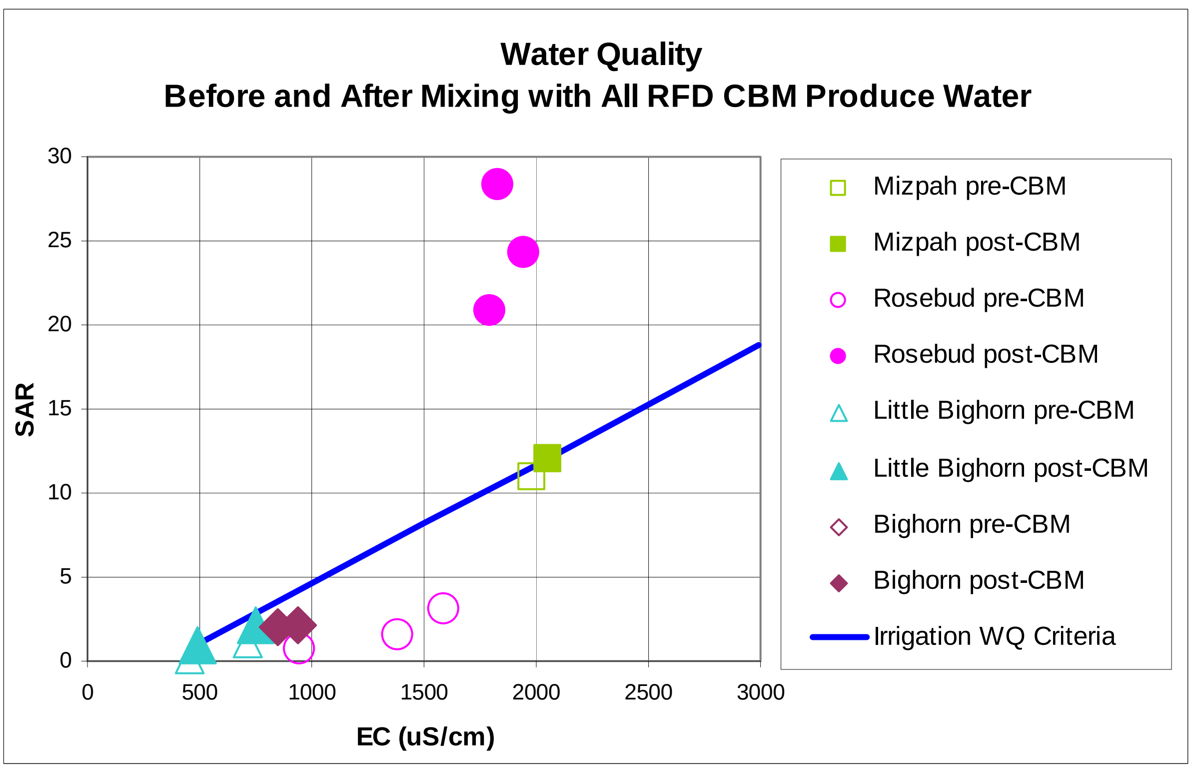
Table 10 .
Summary of Moderate Case Impact Analysis.
Based on Thresholds for Irrigation in MT

Location	Impact to Irrigation (EC and SAR Exceed Threshold)	Impact to Aquatic Life (HCO3 Exceeds Threshold)
Little Powder River ab Dry Creek nr Weston	Potential	
Little Powder River nr Broadus	None	
Powder River at Moorhead	None	
Powder River at Broadus	None	
Mizpah Creek nr Mizpah	Minor	
Tongue River at State Line nr Decker	Adverse	
Tongue R at Birney Day School Br nr Birney	Adverse	
Tongue R bl Brandenberg Bridge nr Ashland	Adverse	
Tongue River at Miles City	Adverse	
Rosebud C at Reservation Bndry nr Kirby	Adverse	
Rosebud Creek nr Colstrip	Adverse	
Rosebud Creek at Mouth near Rosebud	Adverse	
Little Bighorn R bl Pass Cr nr Wyola	Minor	
Little Bighorn River near Hardin	None	
Lower Bighorn River near ST. Xavier	None	
Lower Bighorn River ab Tullock Cr nr Bighorn	None	

Figure 9 shows that the untreated discharge of RFD CBM produced water to streams will adversely impact the Tongue and Rosebud Rivers, rendering those streams unusable for irrigation based on the EC-SAR relationship that represents no reduction in infiltration. All of the streams that meet the no-reduction-in-infiltration criteria also meet the additional limitation on SAR proposed by MT DEQ (SAR <= 12 for the moderate case analysis). However, the Powder River drainages do not meet the additional limitations on EC proposed by MT DEQ (EC <= 2200 for the Powder, Little Powder and Mizpah Rivers; EC <= 1000 for all other streams). The resultant mixed EC of the Little Powder River above Dry Creek is higher than 2200 µS/cm, but this is an improvement over its baseline value of 2890 µS/cm.

Figure 9. Water quality of PRB streams before and after mixing with RFD CBM discharge. Moderate Case Impact Analysis.





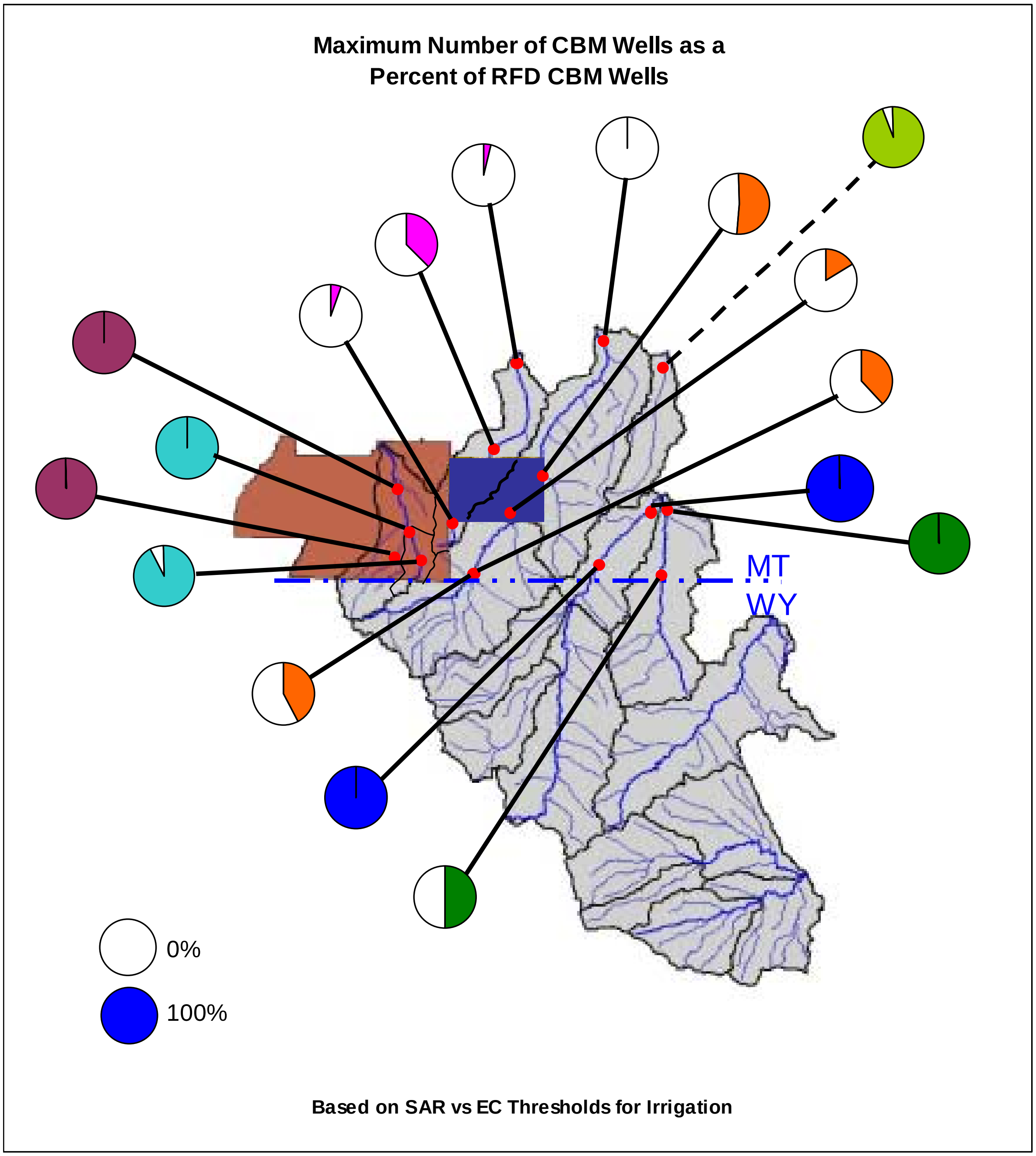
To ensure the Tongue and Rosebud Rivers meet irrigation thresholds that assure no reduction in infiltration, discharge of untreated CBM water needs to be limited. Consequently, the number of wells that discharge directly to the mainstem streams needs to be limited. This analysis uses the EC-SAR relationship to calculate the maximum allowable discharge and, based on the effective discharge rate, the maximum number of allowable discharging CBM wells. Additionally, the assimilative capacity at the stateline stations was split equally between Wyoming and Montana. The calculated limits on CBM discharge and number of CBM wells are listed in Table 11 and depicted in Figure 10. As shown in the table and figure, discharge of untreated CBM produced water to streams needs to be reduced to 50% or less of the RFD numbers in the Little Powder and Tongue drainages in Wyoming and in the Tongue and Rosebud drainages in Montana. Slight reductions may be needed in the Mizpah and Little Bighorn drainages. The limits vary due to differences in baseline water quality in the reaches of the streams, which results in differences in the assimilative capacity of in each reach. Discharge can be maximized in the Little Powder River in Wyoming with no reduction in the projected development on the Montana side if the allocation split at the stateline is 85% WY/ 15% MT.

Table 11.
Limits on CBM Discharge and Number of Discharging CBM Wells to Avoid Exceeding Irrigation Thresholds[1] for Irrigation in Montana.
Moderate Case Impact Analysis.

Location	Discharge Limit (cfs)	Number of CBM Wells	Fraction of RFD CBM Wells (%)
Wyoming			
Little Powder River ab Dry Creek nr Weston	5.1	1010	50
Powder River at Moorhead	RFD	RFD (26598)	100
Tongue River at State Line nr Decker	5.5	1102	43
Montana			
Little Powder River nr Broadus	RFD	RFD (278)	100
Powder River at Broadus	RFD	RFD (3167)	100
Mizpah Creek nr Mizpah	1.1	212	95
Tongue River at State Line nr Decker	5.5	1102	38
Tongue R at Birney Day School Br nr Birney	2.4	469	16
Tongue R bl Brandenberg Bridge nr Ashland	6.6	1322	51
Tongue River at Miles City	0	0	0
Rosebud C at Reservation Bndry nr Kirby	RFD	100	6
Rosebud Creek near Colstrip	1.9	387	22
Rosebud Creek at Mouth nr Rosebud	0	0	0
Little Bighorn R bl Pass Cr nr Wyola	2.4	388	93
Little Bighorn River nr Hardin	RFD	RFD (525)	100
Lower Bighorn River nr ST. Xavier	RFD	RFD (600)	100
Lower Bighorn River ab Tullock Cr nr Bighorn	RFD	RFD (600)	100

[1] Based on no-reduction-in-infiltration EC-SAR relationship.

Figure 10. Limits on number of discharging CBM wells, expressed as percentage of RFD CBM wells, to avoid exceeding EC and SAR thresholds for irrigation in Montana. Moderate Case Impact Analysis.



Restrictive -Case Impact Analysis –Results and Conclusions

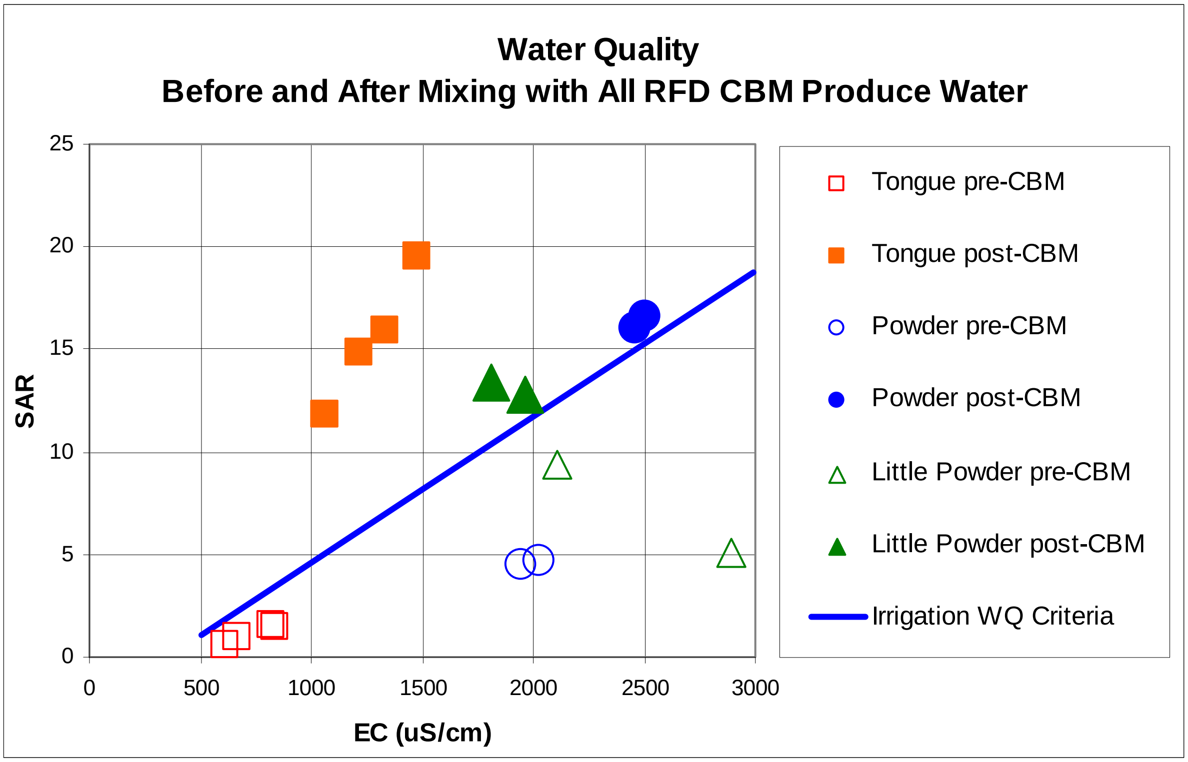
The restrictive-case impact analysis of CBM produced water discharge on surface water quality in PRB streams in Montana is summarized in Table 12 and shown in Figure 11. This analysis is based on the assumptions that CBM wells produced water at an average rate of 10 gpm/well in the first five years with no beneficial use and the discharge is reduced only by 20% due to conveyance loss. The effective discharge to streams in this case is 80% of the amount produced. A mean SAR of 40 and mean EC of 2207 μS/cm were used to represent CBM produced water quality in the Tongue River drainage and all other watersheds to the north of the Tongue. For the Little Powder River drainages, the mean SAR and EC values used were 15 and 1655 μS/cm, respectively. For the Powder River drainages, the mean CBM SAR and EC values used were 22 and 2735 μS/cm, respectively. Median flow rates, along with median values of EC and corresponding SAR values were used to characterize the streams. All upstream development, including development in Wyoming, was evaluated for each watershed.

Table 12.
Summary of Restrictive Case Impact Analysis.
Based on Thresholds[1] for Irrigation in MT.

Location	Impact to Irrigation (EC and SAR Exceed Threshold)	Impact to Aquatic Life (HCO3 Exceeds Threshold)
Little Powder River ab Dry Creek nr Weston	Adverse	
Little Powder River nr Broadus	None	
Powder River at Moorhead	Adverse	
Powder River at Broadus	None	
Mizpah Creek nr Mizpah	Adverse	
Tongue River at State Line nr Decker	Adverse	
Tongue R at Birney Day School Br nr Birney	Adverse	
Tongue R bl Brandenberg Bridge nr Ashland	Adverse	
Tongue River at Miles City	Adverse	
Rosebud C at Reservation Bndry nr Kirby	Adverse	
Rosebud Creek nr Colstrip	Adverse	
Rosebud Creek at Mouth near Rosebud	Adverse	
Little Bighorn R bl Pass Cr nr Wyola	Adverse	
Little Bighorn River near Hardin	Adverse	
Lower Bighorn River near ST. Xavier	Adverse	
Lower Bighorn River ab Tullock Cr nr Bighorn	Adverse	

[1] Based on no-reduction-in-infiltration EC-SAR relationship.

Figure 11. Water quality of PRB streams before and after mixing with RFD CBM discharge. Restrictive Case Impact Analysis.



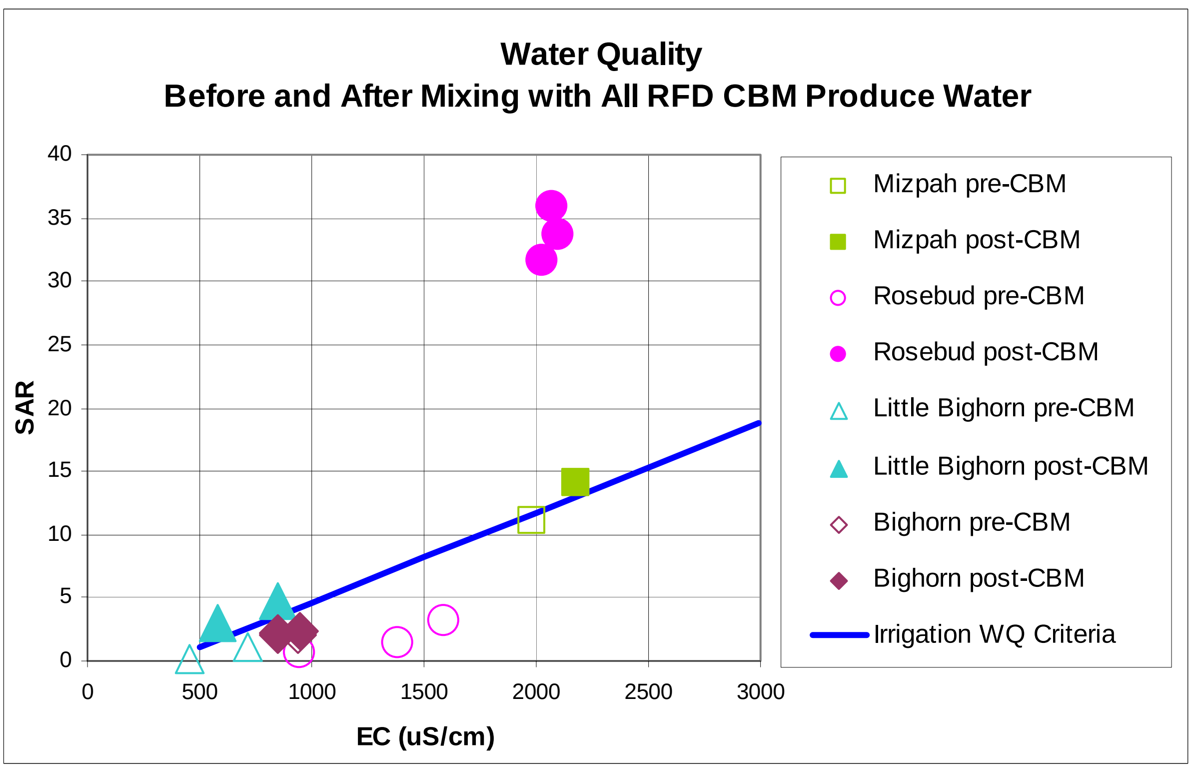


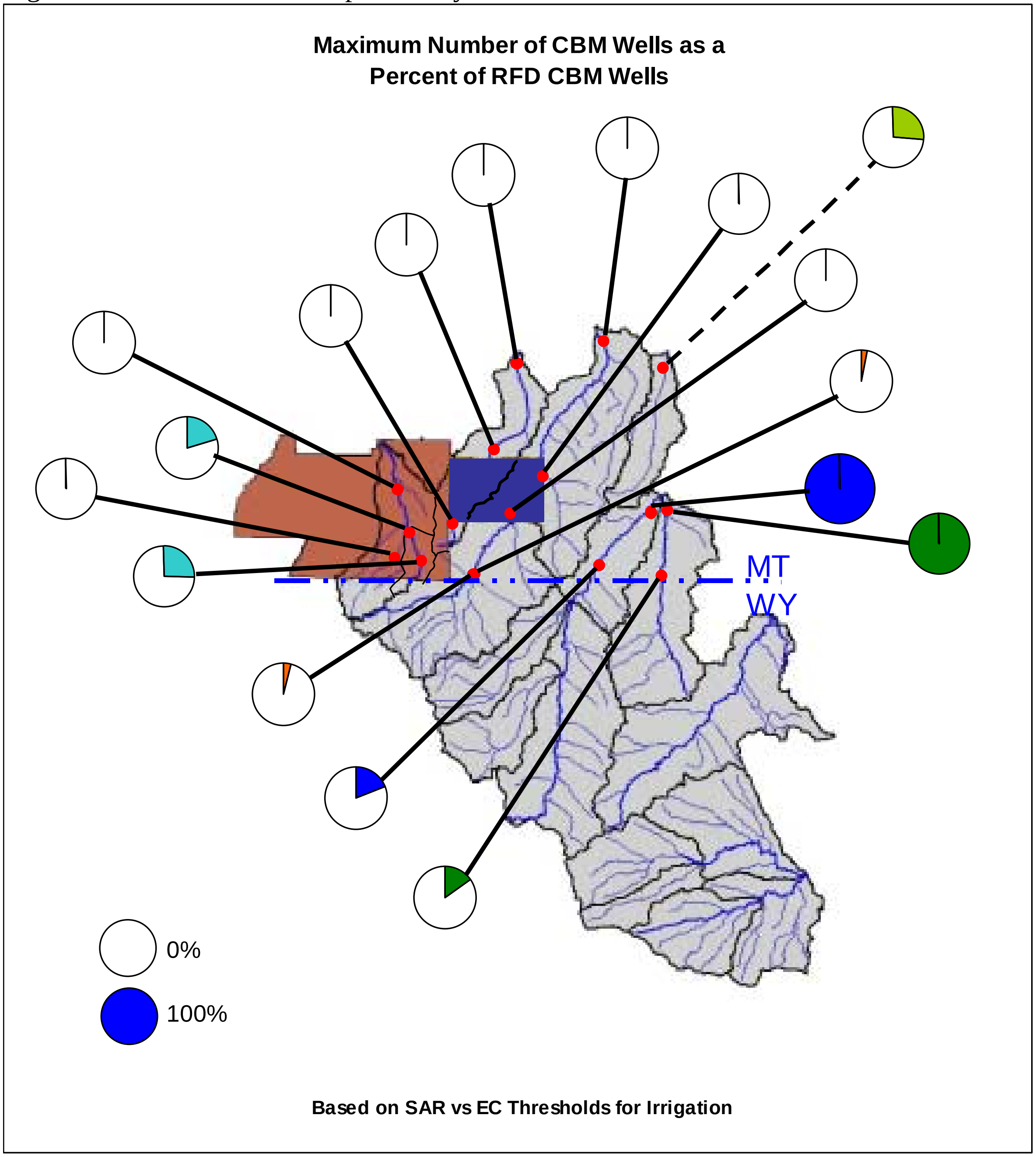
Figure 12 shows that, based on the EC-SAR relationship that represents no reduction in infiltration, the untreated discharge of RFD CBM produced water to streams will adversely impact all rivers except the Bighorn River. If the additional (low level) limitation proposed by MT DEQ for the Bighorn (EC <= 750) is considered, then it too will be adversely impacted. Under this restrictive case scenario, discharge of untreated CBM water needs to be severely restricted in almost all drainages (Table13, Figure 11). In order to meet thresholds for irrigation in Montana, essentially no untreated CBM produced water should be released to the Tongue, Rosebud and Bighorn rivers, less than 20% of the projected discharge can be released to the Little Powder and Powder in Wyoming, and less than 30% of the projected discharge can be released to the Mizpah and Little Bighorn Rivers. The only drainages that can accept all RFD CBM produced water are the Little Powder and Powder in Montana. These drainages have large assimilative capacities relative to the small number of wells projected as part of the RFD.

Table13.
Limits on CBM Discharge and Number of Discharging CBM Wells to Avoid Exceeding Irrigation Thresholds[1] for Irrigation in Montana.
Restrictive Case Impact Analysis

Location	Discharge Limit (cfs)	Number of CBM Wells	Fraction of RFD CBM Wells (%)
Wyoming			
Little Powder River ab Dry Creek nr Weston	5.5	306	15
Powder River at Moorhead	90.5	5075	19
Tongue River at State Line nr Decker	1.7	97	4
Montana			
Little Powder River nr Broadus	RFD	RFD (278)	100
Powder River at Broadus	RFD	RFD (3167)	100
Mizpah Creek nr Mizpah	1.1	60	27
Tongue River at State Line nr Decker	1.7	97	3
Tongue R at Birney Day School Br nr Birney	0	0	0
Tongue R bl Brandenberg Bridge nr Ashland	0	0	0
Tongue River at Miles City	0	0	0
Rosebud C at Reservation Bndry nr Kirby	0	0	0
Rosebud Creek near Colstrip	0	0	0
Rosebud Creek at Mouth nr Rosebud	0	0	0
Little Bighorn R bl Pass Cr nr Wyola	2.4	137	26
Little Bighorn River nr Hardin	1.9	106	20
Lower Bighorn River nr ST. Xavier	0	0	0
Lower Bighorn River ab Tullock Cr nr Bighorn	0	0	0

[1] Based on no-reduction-in-infiltration EC-SAR relationship.

Figure 12. Restrictive Case Impact Analysis.



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